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Metro Toxicant Program
Report Number 2

Municipality of Metropolitan Seattle-METRO, WA

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As part of the U.S. Environmental Protection Agency's Nationwide Urban Runoff Program, the Municipality of Metropolitan Seattle (METRO) studied the sources and presence of toxic substances in urban stormwater runoff, as well as their potential adverse effects on local freshwater receiving environments. Sampling and analysis were designed to provide concentration data for the Clean Water Act's priority pollutant metals and organics. Sampling of potential sources to stormwater runoff included airborne particles, street dust, and catchbasin sediments. Both urban and control environmental samples were taken from interstitial streamwaters, stream sediments, and Lake Washington bottom sediments.

Evaluations of toxicant control measures focused on currently available removal techniques, such as street sweeping, detention basins, and oil separators. The report incorporates a thorough literature review and includes an extensive bibliography.

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METRO

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December 1982

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Municipality of Metropolitan Seattle

TOXICANTS IN URBAN RUNOFF

METRO TOXICANT PROGRAM
REPORT #2

by David V. Galvin
Richard K. Moore

Toxicant Control Planning Section
Water Quality Division
Municipality of Metropolitan Seattle

U.S. Environmental Protection Agency
Grant #P-000161-01
Al Ewing
Project Officer
EPA, Washington Operating Office
Lacey, Washington 90503

December, 1982

DISCLAIMER

Although the research or investigation described herein has been funded in part by the U.S. Environmental Protection Agency through grant No. P-000161-01 to the Municipality of Metropolitan Seattle (Metro), it has not been subjected to the Agency's peer and administrative review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

FOREWORD AND ACKNOWLEDGEMENTS

Toxic substances are ubiquitous in the human environment and are becoming increasingly so in the natural environment from human activities. Recent advances in analytical chemistry allow routine identification of elements and compounds at the part per billion and part per trillion levels in environmental samples, opening new vistas on a complex world of trace substances. Concomitant research in pathophysiology and toxicology has found high tissue levels, tumors and other disease in fish and shellfish in urban waters, with correlation between disease incidence and general toxicant burden in the environment. Red flags have been raised in an area unknown as little as ten years ago. As in all new avenues of science, more questions are formulated than answers provided.

Urban stormwater runoff has been identified for a number of years as a source of peak flooding problems and numerous pollutants in urban streams. It is the major nonpoint source of some contaminants to receiving waters and, as such, has received increased attention nationwide and has been the focus of a major information-gathering program by the U.S. Environmental Protection Agency. Metro's interest in runoff control, as the regional agency responsible for water quality and sewage treatment -- as well as transit -- in the Seattle/King County area, has spanned many efforts, including separation of sewerage systems, combined sewer overflow controls, the RIBCO studies, 208 planning, salmon enhancement in urban streams, regional water quality monitoring and stream resource inventories. Metro has initiated a major toxicant program, including the Toxicant Pretreatment Planning Study, the Toxicant Inventory, the Household Hazardous Waste Disposal Project and other studies, to assess the presence, sources, fates and effects of toxic substances in the sewerage system and local waters. These studies will help Metro and other regional agencies identify problems and formulate effective control programs for point and nonpoint sources of problem toxicants.

Metro received a water quality management grant from the U.S. EPA to study toxicants -- specifically, the Clean Water Act priority pollutants -- in urban stormwater runoff as part of the City of Bellevue's participation in the Nationwide Urban Runoff Program. The U.S. Geological Survey and the University of Washington also participated, directly or through related studies, in the local project. Much cooperation occurred throughout the project between the agencies involved. This assistance, from sample collection to sharing of information and ideas, was essential to the Metro effort.

Pam Bissonnette of the City of Bellevue provided the central coordination and buoyant optimism for all the participants in the

Bellevue study. Dave Renstrom of the City of Bellevue provided the majority of our samples and took on the burdens of special sampler cleaning, sample preparation for shipping, data entry and other additional jobs without complaint. Joy Wherley and Lorrie Murray of Bellevue assisted in this extra effort with good humor.

Joanna Richey of the University of Washington was instrumental in our stream sampling. Her insight, field assistance and constructive comments were invaluable.

Jim Nolan and Boyd Knechtel of the Puget Sound Air Pollution Control Agency provided the suspended air particle samples as well as helpful advice on data interpretation.

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Al Ewing, project officer for U.S. EPA-Region 10, offered assistance in grant administration and much appreciated confidence in and support for our work. His patience with the chronic delays in final report production was legion.

Joe Simmler, Supervisor of the Toxicant Program at Metro, took a major role in the project and provided advice and support throughout. His confidence in his staff and words of encouragement during the tough moments made the job easier. Margaret Coughlan and, before her, Veronica Beecroft and Yvonne Walker provided the crucial clerical support that held the project together. Their quality work and humor under pressure were an inspiration. Raleigh Farlow and Ray Dalseg of the Metro laboratories and Rich Tomlinson of the special projects unit offered technical expertise and critical review of the manuscript.

Elizabeth (Tizzy) Bennett, in the first year, and Richard (Rusty) Moore, through the rest of the project, carried much of the workload and provided the essential review of the literature that forms the substantial part of this report. Most of the report was written by Rusty and reflects his communication skills and insight into a complex topic.

Toxicants in Urban Runoff is a major compilation of available information on a subject important to water pollution control in the Seattle area and throughout the world. While full of valuable data and analysis, it also illustrates the frustrating gaps in our knowledge of the subject, especially the critical issue, "Is it a problem?"

As a component of EPA's Nationwide Urban Runoff Program (NURP), these results will contribute to a better understanding of runoff as a national water quality concern. As a component of Metro's Toxicant Pretreatment Planning Study, the information herein will be factored into the analyses of mass balances, significance of sources, definitions of problems and recommendations for controls in the Seattle area. This report is one piece of a large, mostly unfinished puzzle.

David V. Galvin

Project Manager
Metro - Water Quality

ABSTRACT

As part of the U.S. Environmental Protection Agency's Nationwide Urban Runoff Program, and in conjunction with the City of Bellevue, the U.S. Geological Survey, and the University of Washington, Metro has studied toxic substances in urban stormwater runoff and their potential adverse effects in the aquatic environment. The project included collection and analysis of samples, a comprehensive literature review, and a summary of potential control measures.

Seventy-eight samples were collected in the Seattle metropolitan area between June 1980 and June 1982 and analyzed for the Clean Water Act's priority pollutants. The sampling and analysis scheme was designed to provide local data on both metal and trace organic concentrations in stormwater runoff, in sources to stormwater runoff (airborne particles, street dust, catchbasin sediments, and stormdrain base flows), and in the receiving environment (interstitial streamwater, stream sediments, and Lake Washington sediments).

Most metals and a relatively few trace organic compounds were found in runoff and the urban receiving waters. Many of the priority pollutants in runoff originate from motor vehicles and are adhered to the very fine particles in street dirt. Stormwater transports these particles, eventually discharging them either through the combined sewerage system into wastewater treatment plants, or through separate lines into local streams, lakes, and bays. Due to dilution, flushing, adsorption, and sediment deposition, no acute toxicity problems were discovered in the sites studied. Insufficient data exist for long-term exposure evaluation.

This study recommends further data collection to determine the effects upon aquatic organisms of chronic exposure to toxicant-laden particles in the water column and sediments. Assessments of stormwater's contribution to total toxicant loadings in receiving waters and sediments are needed. Control measures effective at removing fine suspended particles and floatable oils and grease from stormwater appear to be best suited for removing toxicants, where warranted, but additional research specific to toxicant removal is recommended.

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SECTION I

INTRODUCTION

A. AREAWIDE (208) WATER QUALITY PLANNING

Section 208 of the federal Clean Water Act calls for "areawide waste treatment management planning." This includes solutions to municipal and industrial wastes, point source problems, as well as solutions to such areawide nonpoint source problems as storm drainage, accidental spills, and erosion/sedimentation. Under Section 208, each state is required to develop a comprehensive water quality plan and a continuing planning process. In Washington, the state delegated the areawide planning process for the Cedar and Green River Basins to the Municipality of Metropolitan Seattle (Metro). Metro prepared an Areawide Water Quality Plan (Metro, 1978) which identified general problems as well as specific priority water bodies.

The plan found that "...we still have water quality problems, and they are potentially damaging to more water bodies and more recreational opportunities than the original sewage problem in Lake Washington. The major problem we face is control of surface drainage. This urban runoff problem is...subtle, pervasive and difficult to define and deal with..." [emphasis in original].

Five general areas of focus were identified as components of the surface drainage issue. Toxicant control's selection was based primarily on limited but alarming data on heavy metals and a high level of concern for the mostly unknown topic. High priority was assigned to toxicant control to 1) encourage better documentation of suspected toxicant problems, and 2) recommend appropriate measures to control known toxicant problems.

B. METRO'S TOXICANT CONTROL PROGRAM

The recommendations of the 208 plan led Metro to embark on a major toxicant program to gather information about toxic substances in the sewage treatment system. The program, developed in 1979, was designed to assess the presence, sources, fate, and effects of trace substances in Seattle area waters, identify existing or potential problems, and develop control strategies for point and nonpoint sources of problem toxicants. The umbrella project -- known as the Toxicant Pretreatment Planning Study (TPPS) -- is an eight million dollar effort of intense physical, chemical, and biological analyses in the sewage treatment plants, the collection systems and the receiving environment. It was funded in part by the U.S. Environmental Protection Agency and the Washington State Department of Ecology. Metro has developed sophisticated trace metal and trace organic analytical laboratories to support this effort. Over 1,500 samples from the greater Seattle/Central Puget Sound area are being analyzed for a suite of toxic elements at trace (part per billion) levels. Over 1000 organic compounds have been identified to date in the local samples -- which ranged from industrial wastewater and treated sludge to salmon tissue.

To implement the Areawide Plan and assist the TPPS effort, Metro is conducting two special projects to assess nonpoint sources of toxicants. The first, a study of toxic substances in consumer products and the impacts of their disposal, is known as the Household Hazardous Waste Disposal Project. The second project is a study of toxic substances in urban stormwater runoff called the 208 Toxicant Inventory. This document is the final report of the latter project, and is a vital component of Metro's comprehensive toxicant control progam.

C. THE NATIONWIDE URBAN RUNOFF PROGRAM

The potential water quality impacts of urban drainage were recognized before the landmark Federal Water Pollution Control Act of 1972, but that law added major emphasis to nonpoint sources and their control through "best management practices" (BMPs) and the 208 planning process. Most of the 208 plans began with the assumption that runoff was a major problem and proceeded to recommend theoretical BMPs for runoff control. By 1977, with the passage of the Clean Water Act, the uncertainties of this approach resulted in a cutoff of federal funds for treatment of separate storm water discharges until such time as adequate data were available to answer fundamental questions on runoff loads, runoff impacts, effectiveness of control measures and the costs of implementing controls. The U.S. Environmental Protection Agency established a five-year Nationwide Urban Runoff Program (NURP) to address these issues and to determine on a national scale:

- The nature of urban runoff problems;
- The causes of these problems (e.g., sources, transport modes, impacts);
- The severity of these problems based on consideration of beneficial uses and water quality standards; and
- Opportunities for controlling urban runoff problems (U.S. EPA 1982a).

The urban runoff program is based on 28 data-gathering projects around the country representing diverse climates, landuse types, receiving waters, and control approaches (USEPA, 1982a). Each project is a self-contained local study addressing local water quality and management needs. In addition, an extensive national data base is being built to include runoff concentrations and loads, water quality impacts on receiving waters, and effectiveness of controls. Both the local results and the national analysis will contribute useful information on the basic issues of urban runoff.

One of the 28 urban runoff study areas is the city of Bellevue, Washington (see Figure 2 in Section II). The Bellevue Urban Runoff Project is a conglomerate of four overlapping and complementary studies involving four separate agencies: the city of Bellevue, the U.S. Geological Survey, and Metro (all with EPA Nationwide Urban Runoff Program funding), and the University of Washington (with EPA Office of Research and Development funding).

The city of Bellevue's Street Sweeping Demonstration Project is focusing on rainfall, runoff, and street dust relationships in two of its residential drainage basins. It is studying street sweeping as a best management practice (BMP) for runoff pollution abatement, and collecting samples of dry street dust and composite stormwater runoff from every major rainstorm.

The U.S. Geological Survey is collecting data on rainfall and runoff to develop urban watershed models and test best management practices for both street sweeping and stormwater detention. Their sampling sites include the two residential basins studied by Bellevue, as well as a third suburban arterial's basin for detention studies. All three basins are within the Kelsey Creek watershed. Sampling includes rainfall, dryfall, wetfall, and stormwater runoff by discrete collection (many samples taken over the hydrograph) from a limited number of rainstorms.

The University of Washington's civil engineering department is studying the effects of urbanization on small streams. This study documents the physical, chemical, and biological characteristics of the Kelsey Creek watershed as well as a non-urban control stream (Bear Creek).

The final component of the Bellevue Urban Runoff Project is Metro's Toxicant Inventory. The inventory is providing trace metal and organic analyses for all three of the above projects. The results of these toxicant analyses are provided in this report. The other projects are preparing separate reports (all pending at this time), each of which will be essential to full understanding of the Toxicant Inventory information. A summary of the components of the Bellevue Urban Runoff Project is planned by all participating agencies.

D. CONVENTIONAL POLLUTANTS, PRIORITY POLLUTANTS, AND WATER QUALITY CRITERIA

Human activity has consistently altered levels of certain natural water quality parameters. These include such chemical, physical, and biological variables as total suspended solids (TSS), temperature, acidity (pH), biochemical oxygen demand (BOD), oil and grease, nitrogen and phosphorus (algal nutrients), and fecal coliform bacteria levels (a non-pathogenic indicator of possible pathogen contamination). Historically, these have been the focus of wastewater management and water quality planning and have come to be known as the conventional pollutants.

Only within the last few years have analytical techniques become sophisticated enough to detect trace amounts of toxic inorganic and organic chemicals in aquatic environments. With heightened public awareness of water quality issues, attention has focused on the wide dispersion and potentially harmful effects of these invisible contaminants. The Federal Water Pollution Control Act of 1972 required the development of industrial effluent guidelines, pretreatment standards, and prioritization of toxic chemicals to comply with aquatic life and public safety criteria.

Impatient with four years of implementation delays by the Environmental Protection Agency, several environmental groups filed a lawsuit in 1976. Part of the resulting settlement agreement required the EPA to establish maximum exposure criteria and effluent limitations for 65 toxic chemical groups of special concern (see list in Table 1). The Clean Water Act of 1977, an attempt to strengthen and clarify federal water quality policy, incorporated these 65 chemical groups and applied tighter controls and limitations for toxicants than those controls under the 1972 Water Pollution Control Act.

Because the 65 toxic groups include thousands of individual chemicals, monitoring and control measures for each would be prohibitive. An expanded list of 129 inorganic and organic chemicals was selected (Sittig, 1980; Keith and Telliard, 1979) based on volume of production or use, chemical stability, potential for water contamination and capability of analytical detection. The specific toxic chemicals in this list are referred to as the priority pollutants (see Table 2). Figure 1 gives a few structural examples of the organic priority pollutant compounds. Provision for periodic addition or deletion of chemicals based on new research and literature reviews was incorporated into the regulations. Since its initial compilation in 1978, three compounds have been dropped from the priority pollutant designation. The current list of 126 toxic chemicals is by no means an all-inclusive compendium of environmentally hazardous materials. Many other compounds, both known and unknown, could pose serious aquatic problems.

Lack of technical information and analytical ability are the primary limiting factors in expanding the list. Although asbestos is one of the 126 priority pollutants, it has not been included in Nationwide Urban Runoff studies because it is found in many forms, and is costly to analyze and difficult to detect.

Section 304(a) of the Clean Water Act requires the EPA to publish water quality criteria based on the latest scientific knowledge of the effects of priority pollutants on aquatic life. The objective is to preserve both the health of the organisms and their potential public value. These criteria are to be based on toxicological data alone and not on economic or technological feasibility. The act stresses that the criteria represent only scientific assessments of ecological effects. Although they do not carry any regulatory weight by themselves, the criteria should serve as guidelines for establishing state water quality standards.

Since toxicities vary depending upon whether the receiving waters are fresh or salt, separate priority pollutant criteria are recommended for each compound. Each criterion should also consist of two concentration values: one not to be exceeded as a 24-hour average (the chronic toxicity value), and the other as a maximum value never to be exceeded (the acute toxicity value). Due to the current lack of applicable data, criteria values for the inorganics and pesticides are only partially completed, and no values are available for the remaining organic chemicals (U.S. EPA 1980a). Table 3 presents those substances for which criteria have been set.

Numerous studies caution that only when the inorganic priority pollutants exist as free metallic ions are they highly toxic to aquatic organisms (Florence, 1977, Novotny and Chesters, 1981). Likewise, the EPA's toxicity criteria were determined by noting the concentrations of dissolved metallic salts which killed at least 50% of the test organisms over a specified time interval (Sittig, 1980). However, these same studies note that [illegible] the natural environment these metals are generally not in forms that readily yield free ions. Applying the toxicity criteria to these non-ionic concentrations could suggest a greater threat to the aquatic organisms than actually exists. This point is addressed further in the Discussion and Analysis section of this report.

Table 1. THE 65 PRIORITY POLLUTANT CLASSES
(U.S. EPA, 1980a)

(1) Acenaphthene
(2) Acrolein
(3) Acrylonitrile
(4) Aldrin/Dieldrin
(5) Antimony and compounds
(6) Arsenic and compounds
(7) Asbestos
(8) Benzene
(9) Benzidine
(10) Beryllium and compounds
(11) Cadmium and compounds
(12) Carbon tetrachloride
(13) Chlordane and metabolites
(14) Chlorinated benzenes
(15) Chlorinated ethanes
(16) Chloroalkyl ethers
(17) Chlorinated naphthalenes
(18) Chlorinated phenols
(19) Chloroform
(20) 2-Chlorophenol
(21) Chromium and compounds
(22) Copper and compounds
(23) Cyanides
(24) DDT and metabolites
(25) Dichlorobenzenes
(26) Dichlorobenzidine
(27) Dichloroethylenes
(28) 2,4-Dichlorophenol
(29) Dichloropropane and dichloropropene
(30) 2,4-Dimethylphenol
(31) Dinitrotoluene
(32) Diphenylhydrazine
(33) Endosulfan and metabolites
(34) Endrin and metabolites
(35) Ethylbenzene
(36) Fluoranthene
(37) Haloethers
(38) Halomethanes
(39) Heptachlor and metabolites
(40) Hexachlorobutadiene
(41) Hexachlorocyclohexane
(42) Hexachlorocyclopentadiene
(43) Isophorone
(44) Lead and compounds
(45) Mercury and compounds
(46) Naphthalene
(47) Nickel and compounds
(48) Nitrobenzene
(49) Nitrophenols
(50) Nitrosamines
(51) Pentachlorophenol
(52) Phenol
(53) Phthalate esters
(54) Polychlorinated biphenyls
(55) Polynuclear aromatic hydrocarbons
(56) Selenium and compounds
(57) Silver and compounds
(58) 2,3,7,8-tetrachlorodibenzo-p-dioxin
(59) Tetrachloroethylene
(60) Thallium and compounds
(61) Toluene
(62) Toxaphene
(63) Trichloroethylene
(64) Vinyl chloride
(65) Zinc and compounds

Table 2. THE EXPANDED LIST OF THE 126 PRIORITY POLLUTANTS (U.S. EPA, 1980a)

METALS AND OTHER INORGANICS

Antimony
Arsenic
Asbestos
Beryllium
Cadmium
Chromium
Copper
Cyanide
Lead
Mercury
Nickel
Selenium
Silver
Thallium
Zinc

PESTICIDES

Acrolein
Aldrin
Chlordane
DDD
DDE
DDT
Dieldrin
Endosulfan and Endosulfan Sulfate
Endrin and Endrin Aldehyde
Heptachlor
Heptachlor Epoxide
Hexachlorocyclohexane (α,β,δ, isomers)
γ-Hexachlorocyclohexane (Lindane)
Isophorone
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)
Toxaphene

Table 2 (continued). THE EXPANDED LIST OF THE
126 PRIORITY POLLUTANTS
(U.S. EPA, 1980a)

HALOGENATED ALIPHATIC HYDROCARBONS

Chloromethane (Methyl Chloride)
Dichloromethane (Methylene Chloride)
Trichloromethane (Chloroform)
Tetrachloromethane (Carbon Tetrachloride)
Chloroethane (Ethyl Chloride)
1,1-Dichloroethane (Ethylidine Chloride)
1,2-Dichloroethane (Ehtylene Dichloride)
1,1,1-Trichloroethane (Methyl Chloroform)
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
Hexachloroethane
Chloroethene (Vinyl Chloride)
1,2-*trans*-Dichloroethene
Trichloroethene
Tetrachloroethene (Perchloroethylene)
1,2-Dichloropropane
1,3-Dichloropropene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Bromomethane (Methyl Bromide)
Bromodichloromethane
Dibromochloromethane
Tribromomethane (Bromoform)

MONOCYCLIC AROMATIC HYDROCARBONS

Benzene
Chlorobenzene
1,2-Dichlorobenzene (*o*-Dichlorobenzene)
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene)
1,2,4-Trichlorobenzene
Hexachlorobenzene
Ethylbenzene
Nitrobenzene
Toluene
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Phenol
2-Chlorophenol
2,4-Dichlorophenol
2,4,6-Trichlorophenol
Pentachlorophenol
2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
2,4-Dimethyl phenol
p-Chloro-*m*-cresol
4,6-Dinitro-*o*-cresol

Table 2 (continued). THE EXPANDED LIST OF THE 126 PRIORITY POLLUTANTS (U.S. EPA, 1980a)

POLYCYCLIC AROMATIC HYDROCARBONS

Acenaphthene
Acenaphthylene
Fluorene
Naphthalene
Anthracene
Fluoranthene
Phenanthrene
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Chrysene
Pyrene
Benzo(ghi)perylene
Benzo(a)pyrene
Dibenzo(a,h)anthracene
Indeno(1,2,3-cd)pyrene

HALOGENATED ETHERS

Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)ether
2-Chloroethyl vinyl ether
4-Chlorophenyl phenyl ether
4-Bromophenyl phenyl ether
Bis(2-chloroethoxy)methane

PHTHALATE ESTERS

Dimethyl Phthalate
Diethyl Phthalate
Di-n-butyl Phthalate
Di-n-octyl Phthalate
Bis(2-ethylhexyl)Phthalate

POLYCHLORINATED BIPHENYLS AND RELATED COMPOUNDS

PCB-1016
Aroclor 1221
Aroclor 1232
Aroclor 1242
Aroclor 1248
Aroclor 1254
Aroclor 1260
2-Chloronaphthalene

NITROSAMINES AND OTHER N COMPOUNDS

Dimethyl nitrosamine
Diphenyl nitrosamine
Di-n-propyl nitrosamine
Benzidine
3,3'-Dichlorobenzidine
1,2-Diphenylhydrazine (Hydrazobenzene)
Acrylonitrile

Table 3. WATER QUALITY CRITERIA
(U.S. EPA, 1980a)

	EPA Ambient Water Quality Criteria			
	Freshwater		Saltwater	
Toxic Chemical Groups	Acute	Chronic	Acute	Chronic
Metals and Inorganics				
Arsenic (trivalent)	440	NCA	NCA	NCA
Cadmium (total)	See EQN	See EQN	59	4.5
Chromium (trivalent)	See EQN	NCA	NCA	NCA
Chromium (hexavalent)	21	0.29	1260	18
Copper (total)	See EQN	5.6	23	4.0
Cyanides (free ion)	52	3.5	NCA	NCA
Lead (total)	See EQN	See EQN	NCA	NCA
Mercury (total)	4.1	0.2	3.7	0.10
Nickel (total)	See EQN	See EQN	140	7.1
Selenium (inorganic selenite)	260	35	410	54
Silver (total)	See EQN	NCA	2.3	NCA
Zinc (total)	See EQN	47	170	58
PCBs				
All PCBs combined	NCA	0.014	NCA	0.030
Pesticides				
Aldrin	3.0	NCA	1.3	NCA
Chlordane	2.4	0.0043	0.09	0.0040
DDT	1.1	0.001	0.13	0.001
Dieldrin	2.5	0.0019	0.71	0.0019
Ednosulfan	0.22	0.056	0.034	0.0087
Endrin	0.18	0.0023	0.037	0.0023
Heptachlor	0.52	0.0038	0.053	0.0036
Lindane (Gamma-BHC)	2.0	0.080	0.16	NCA
Toxaphene	1.6	0.013	0.070	NCA

NCA = No Criterion Available
See EQN = See equations

EQUATIONS:

EPA ambient water quality criteria for several of the metals are dependent upon water hardness and are derived using the following equations ($\mu g/l$).

Cadmium: freshwater acute = $e^{(1.05(\ln(\text{hardness})) -3.73)}$

freshwater chronic = $e^{(1.05 (\ln(\text{hardness})) -8.53)}$

Chromium (trivalent): freshwater acute = $e^{(1.08 (\ln(\text{hardness})) +3.48)}$

Copper: freshwater acute = $e^{(0.94 (\ln(\text{hardness})) -1.23)}$

Lead: freshwater acute = $e^{(1.22 (\ln(\text{hardness})) -0.47)}$

freshwater chronic = $e^{(2.35 (\ln(\text{hardness})) -9.48)}$

Nickel: freshwater acute = $e^{(0.76 (\ln(\text{hardness})) +4.02}$

freshwater chronic = $e^{(0.76 (\ln(\text{hardness})) +1.06)}$

Silver: freshwater acute = $e^{(1.72 (\ln(\text{hardness})) -6.52)}$

Zinc: freshwater acute = $e^{(0.83 (\ln(\text{hardness})) +1.95)}$

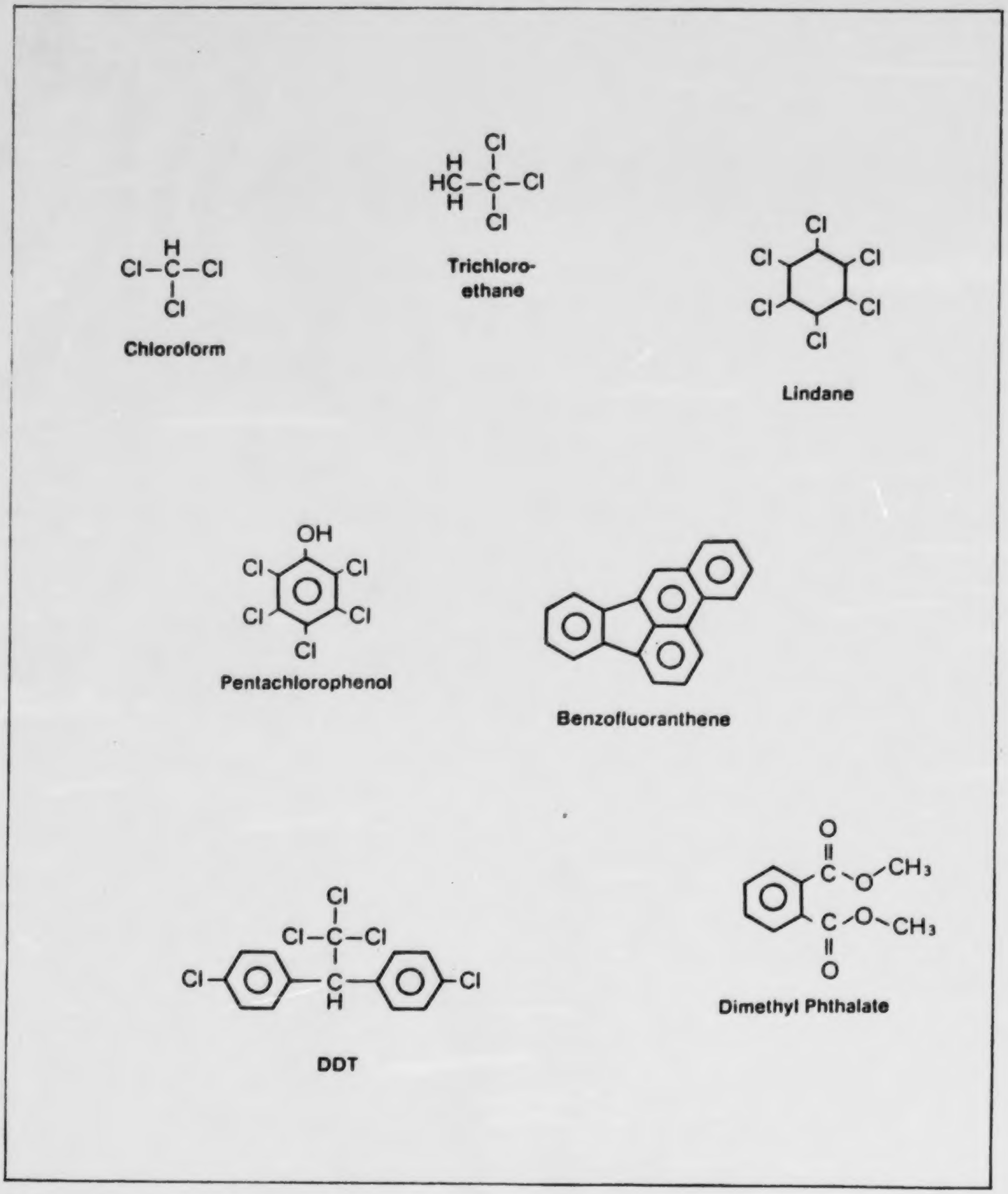
Chloroform
Trichloroethane
Lindane
Pentachlorophenol
Benzofluoranthene
DDT
Dimethyl Phthalate

Figure 1.
STRUCTURES OF EXAMPLE ORGANIC PRIORITY POLLUTANTS

SECTION II

THE TOXICANT INVENTORY STUDY DESIGN

A. GOALS AND OBJECTIVES OF THE PROJECT

The goal of the Toxicant Inventory, as stated in the Revised Work Plan (Metro, 1981), was "to define the presence of priority pollutants and other toxicants in urban runoff and other nonpoint sources in order to assess potential problems and evaluate best management practices (BMPs) for their control."

Specific objectives of the project were:

1. To identify toxic substances in urban runoff, in nonpoint sources to urban runoff, and in the receiving water environment through field sample collection and analyses;
2. To review the literature and develop a comprehensive picture of the state-of-the-art knowledge of nonpoint sources of toxic substances;
3. To assess the problem of toxic substances in urban runoff, in other nonpoint sources and in the receiving water environment, based on results from objectives 1 and 2 above;
4. To evaluate potential control measures, including their cost effectiveness;
5. To develop best management practices (BMPs) and an implementation plan to control toxicants from nonpoint sources found in high concentrations in the Seattle/King County area;
6. To initiate implementation of the preferred plan through the pertinent governmental jurisdictions in the Seattle metropolitan area; and
7. To provide toxicant data to the Bellevue Urban Runoff Project, the U.W. Urban Streams Project, and other related studies to expand the scope of study and aid in data interpretation (Metro, 1981).

The project, which evolved over two and a half years, began when little was known about toxic substances in urban runoff. The project was conceived with expectations that all the information necessary to reach conclusions and to control problems would be available. Definitive data would be collected, complete water quality criteria promulgated by EPA, problems and hot spots identified, and control measures implemented. As this report shows, such expectations were unrealistic given the nature of the toxicant issue, the uncertainties of analyzing substances at the part per billion and part per trillion level, and the extraordinary lack of data on the substances in question. Much useful information has been produced, but the subject remains filled with unknowns.

B. EXPERIMENTAL DESIGN

1. Literature Review

The literature review's objective was to determine the extent of current knowledge of priority pollutants both as contaminants of urban runoff and as toxicants to receiving-water biota.

(a) Scope of the Review. The literature review was designed to examine the following topics: the concentrations of the priority pollutants as constituents of urban runoff; the sources, pathways and fates of these priority pollutants; the relative importance of urban runoff as a carrier of these materials; the physical and chemical form of each substance as it moves through the environment; the toxicities of the priority pollutants to various aquatic organisms and the influence of other water quality parameters; and the effectiveness of potential control measures on priority pollutants at their source and in urban stormwater runoff.

(b) Selected Sources. Numerous documents were consulted as possible sources of information for this study. The following categories proved to be the most useful: Metro study summaries; U.S. EPA research summaries; professional and scientific journals; environmental engineering handbooks; National Technical Information Service bibliographies; and literature reviews, especially the Dalton, Dalton, and Newport report entitled, Priority Pollutants in Urban Stormwater Runoff: A Literature Review (Rolan et al., N.D.). Experts from the University of Washington and other universities and research centers across the country also provided valuable updates for this rapidly evolving field of study.

2. Environmental Monitoring

Metro's Toxicant Inventory environmental monitoring program collected 78 samples in the Seattle metropolitan area between June 1980 and June 1982 for analysis of priority pollutant content (metals, cyanides, pesticides, and organics). Table 4 presents a summary of sample types, numbers and dates collected. The sampling scheme was designed to provide local data for stormwater runoff -- by collecting flow-proportioned composite samples of urban stormwater; sources to runoff -- by collecting airborne particulate matter, street dirt, catchbasin sediments, and storm drain base flows; and the receiving environment -- by collecting interstitial streamwater, stream sediments, and Lake Washington nearshore and deep lake sediments.

Sampling was designed to dovetail with other Bellevue Urban Runoff Project studies (as described in Section I C). Personnel from the city of Bellevue and University of Washington's Civil Engineering Department provided valuable assistance in conventional sampling design and collection. Metro provided priority pollutant data.

For a complete analysis of the relationships between priority pollutants and conventional parameters, the final reports for each of the other Bellevue Urban Runoff Program participants must be reviewed as they become available. Due to the different schedules for data analysis and final report preparation, these statistical relationships could not be included in this Toxicant Inventory report.

(a) The Study Area. Seattle and Bellevue are cities located within King County, Washington. They lie in the Puget Sound lowlands on the west side of the Cascade Mountains (see Figure 2). Topography consists of rolling hills of glacial debris and the three major water bodies: Puget Sound to the west, Lake Washington between the cities, and Lake Sammamish to the east.

The area's west coast maritime climate is protected from the more intense winter storms from the Pacific Ocean by the Olympic Mountains. Prevailing air movement in the fall, winter, and early spring is from the southwest, and summer winds come from the northwest. These northwest winds provide a well-defined summer dry season, as shown in Figure 3. Precipitation results from orographic lifting of warm, moist, marine air by the Cascade Mountains, producing a winter rainfall pattern with as many as 100 measurable, though generally light-intensity, storms per year. Mean annual precipitation, as shown by the isohyets of Figure 4, increases dramatically from west to east within the study area, from approximately 35 inches (89 cm) in Seattle to over 45 inches (114 cm) in eastern Bellevue. Almost all of the precipitation in the Seattle/Bellevue area falls as rain.

All of the stormwater and most of the street dust samples for this project came from the two Bellevue study neighborhoods, Surrey Downs and Lake Hills (see Figure 5). Following are the site characteristics for these two drainage basins (from Bellevue data):

Surrey Downs:

- Area of the drainage basin: 95 acres.
- Landuse: 95 acres (100%) contain 2.5 to 8 dwelling units

per acre (a residential average of 3.0 units per acre), including 28 acres (29%) of impervious surfaces.

- Streets: 6.2 lane miles of asphalt, 65% in good condition, 33% in fair condition and 2% in poor condition. 84% are served with curbs and gutters.
- Traffic: the area is relatively isolated from neighboring communities due to limited vehicular access.
- Drainage: 100% separate storm sewers.

Lake Hills:

- Area of drainage basin: 102 acres.
- Landuse: 92 acres (90%) contain 2.5 to 8 dwelling units per acre (a residential average of 3.5 units per acre), including 34 acres (37%) of impervious surfaces.
- Streets: 9.7 lane miles of asphalt, 94% in good condition, and 6% in fair condition. 100% are served with curbs and gutters.
- Traffic: two through streets carry more traffic than other residential streets.
- Drainage: 100% separate storm sewers.

As part of the street sweeping study for the Bellevue Urban Runoff Project, the two basins were used to test mechanical brush sweeping for removal efficiency and impacts on stormwater runoff quality. While one basin was being swept three times per week for a period of approximately nine months, the other was being left unswept as a control. After two months of no sweeping for either basin, the sweeping and control patterns were reversed.

(b) Sampling Procedures. Analysis of environmental samples for trace constituents demands close attention to cleanliness in order to avoid contamination. Special cleaning protocols (as outlined in U.S. EPA, 1980b) were followed for all surfaces that came in contact with the samples during collection, shipping and analysis. Only surfaces of high quality glass, Teflon®, stainless steel, or aluminum were inert enough and capable of being cleaned thoroughly enough to satisfy the rigorous demands of the highly sensitive analytical techniques. Deionized distilled water was used to create blank samples when appropriate during the field collection process as part of the quality assurance/quality control program.

- Stormwater Runoff Sampling: Runoff samples were collected by city of Bellevue personnel in the Surrey Downs and Lake Hills basins as flow-proportional composite samples. These were collected with Manning (model S-3000T) automated samplers triggered by ultrasonic flowmeters (model UF-1100). Volatiles were collected, when possible, as single discrete samples early in each storm event; otherwise they were split from the composite sample. Blank samples were run through the samplers, after cleaning, prior to each succeeding storm event. Samples were split into appropriate containers, iced, and sent air express to the analytical laboratory.

- Sampling the Sources to Runoff: Potential sources and pathways of toxicants to urban runoff were sampled to obtain some idea of the types of priority pollutants associated with them and the order-of-magnitude concentration differences. These potential sources included atmospheric suspended particles, street dust, stormwater catchbasin sediment, and base flow water in the storm drains.

-- Atmospheric Suspended Particles. An examination of atmospheric suspended particles as potential contributors of priority pollutants to urban stormwater runoff was desired for this study. But due to the cost, complexity, and extended sampling duration required to obtain measurable amounts of either dryfall or wetfall particles, Metro researchers chose to analyze high-volume air filters instead; but these were found to have limitations of their own. Hi-vol filters were designed to capture both aerosols and ultra-fine particles. This material tends to remain suspended in the atmosphere for long periods of time and is not appreciably affected by either dryfall or wetfall. Since these particles do not readily accumulate as street dust, analytical results are not directly comparable with street dust concentrations. However, comparisons of the types of toxicants identified and their relative ranking within each sample is worth noting.

Metro arranged with the Puget Sound Air Pollution Control Agency to obtain two sets of exposed air filters. Each group of 8 1/2 by 11-inch glass fiber mats filtered air for a continuous 24-hour period at a rate of approximately 50 cubic feet per minute while mounted in a standard high-volume air sampler. EPA air sampling methodology for total suspended particulate matter was followed in each case. The sampler was located on the roof of the Metro pump station at 4401 East Marginal Way South, Seattle -- an area of heavy industry (see Figure 6).

The first set of samples obtained from PSAPCA was a composite of 40 filters collected between January and October, 1976. These filters had high particle loadings. The second set of filters was a composite of ten recently collected filters taken during December, 1981. The analytical laboratory prepared and ran each set of filters as one composite priority pollutant sample. Along with each set of exposed filters, a set of unexposed filters (blanks) was included to check for background contamination of the glass fiber mats. All filters were analyzed using sediment sample protocol.

-- Street Dust. Acting as an extensive network of impervious water channels, street surfaces can become a major contributor to the urban stormwater collection system. Much of the load of suspended particles found in stormwater has been attributed to the washing off of accumulated street dust (Novotny and Chesters, 1981; Sartor and Boyd, 1972). In order to evaluate the significance of street dust as a contributor of priority pollutants to the study area's receiving water environment, samples were taken from street surfaces serving a variety of land uses in the Seattle-Bellevue area. Sampling was performed by Bellevue personnel using stainless steel, industrial, wet-dry vacuum units supplied with dacron filter bags and a 35-foot length of flexible PVC hosing fitted with a wand and a six-inch wide "gulper" mouth. Samples were taken in a series of half-street strips extending from crown to curb.

Dust was vacuumed from various streets within the Surrey Downs and Lake Hills residential basins in Bellevue. Additional Bellevue samples were taken from 148th Avenue Southeast (see Figure 5), a divided four-lane arterial, in order to compare high and low traffic volume effects. Three sites were chosen within the city of Seattle to examine an industrial zone, a commercial zone, and a street within the central business district. For the industrial site, street dust was taken along 4th Avenue South near South Michigan Street. A section of Elliott Avenue north of Harrison Street was selected as the commercial-arterial site. Within the Seattle central business district, Third Avenue from Virginia Street to Marion Street was sampled. (See Figure 6 for sampling site locations.)

-- Detention Basin Sediment. The stormwater control structure at 148th Street Southeast in Bellevue is a deep concrete box with an adjustable weir which slows down the flow of stormwater and causes the heavier suspended sediment to settle out; but the turbulence from high volumes of runoff probably resuspends much of the finer sedimentary material (Sartor and Boyd, 1972). The basin drains approximately 5,000 feet of the four-lane divided arterial and its adjacent sidewalks and parking areas. Random samples of the depositional mud and organic debris were taken during a low flow period.

- Base Flow Water. Both the Surrey Downs and the Lake Hills storm drainage systems have small but continuous base flows from infiltration between storm events. Random samples were taken from each basin in order to determine background levels of the priority pollutants.

- Receiving Environment Sampling: Many of the storm drains in the city of Seattle and most of the storm drains outside of Seattle in the metropolitan area end with outfalls into local streams or lakes. Metro investigated priority pollutant accumulation in receiving waters to determine levels contributed by urban runoff. Samples were taken of interstitial water (slow-moving water within the bottom gravel of the stream -- an important habitat for many stream organisms), bottom sediments in the streams, and bottom sediments in near-shore and central basin Lake Washington sites. (See Figure 7 for sampling site locations.)

  - Interstitial Streamwater. Fieldwork for the interstitial sampling was coordinated with the University of Washington's Department of Civil Engineering study of the impacts of stormwater runoff on urban streams (see Richey, 1982). Water was sampled from perforated aluminum standpipes driven twelve inches (30 centimeters) into the bottom sediments of Kelsey Creek, an urban stream, and Bear Creek, a rural background reference stream (see Figure 7). A Manning S-3000T sampler pumped the interstitial water out of the pipes through a teflon hose.

  - Stream Bottom Sediments. Metro personnel took samples of stream bottom sediments from three urban streams, Kelsey Creek, Thornton Creek, and Juanita Creek, and from the rural reference stream, Bear Creek (see Figure 7). In the first phase of collection, an aluminum scoop was dug into the streambed and emptied into glass containers. The second phase made use of a new procedure recently adopted by Metro's stream monitoring personnel -- freeze-core sampling. The closed, pointed end of a meter-long, 2.5 centimeter wide, stainless steel tube is forced 30 centimeters into the bottom sediments. The tube is then flooded with liquified carbon dioxide for three to five minutes to super-cool the metal and freeze a 10- to 15-centimeter diameter core of interstitial water and sediments. This frozen core is then extracted along with the tube and chipped off into the glass containers. Freeze-coring results in a deeper, more uniform sample with no loss of finer, silt-like materials.

  - Lake Washington Bottom Sediments. The two sets of Lake Washington bottom sediment samples represent an attempt to characterize priority pollutant accumulation both at stream mouth alluvial deposits and below the lake's major storm drain outfalls. The first set of samples was from sites within shallow embayments, some fed by streams, some not. The selection of specific sites and supervision of sampling crews was conducted by Metro's Water Quality Monitoring and Analysis Section. Data will be used for both groups' studies. The following seven locations were sampled (see Figure 8): Lyons Creek mouth, Juanita Creek mouth, Andrews Bay, Union Bay, Fairweather Bay, and Yarrow Bay. Only Andrews Bay and Union Bay are not directly fed by streams.

Samples, collected by boat crews, were obtained by lowering a VanVeen sediment sampler (a clam shell-type grab sampler) at five adjacent spots within the sample site. From within the center of each sample -- not in contact with the sampler's sides -- a two-centimeter-deep core was taken with an aluminum "cookie cutter." The five cores were then blended to yield a homogenous, representative bottom sample for each site.

The second sampling set consisted of Lake Washington bottom sediments split with those taken for the Metro TPPS project. Sampling sites were chosen to examine potential transport and deposit of priority pollutants from near-shore stormwater outfalls to deep lake sediments. Figure 8 identifies the following sampling locations: Control site #2 was chosen as a near-shore background reference; samples were taken from the depositional zones below storm drain #20 and Juanita Bay's mouth, the final sample site was mid-lake station #0550. Metro crews used the same sampling procedures as with the first sampling set.

(c) Analytical Methods and Quality Assurance. As described in section I D, the priority pollutants are a diverse group of toxic substances composed of 13 elements (heavy metals), cyanides, asbestos, and 111 organic compounds. (See Table 2 for a complete list.) Most of these substances are found in environmental samples in minute concentrations ranging from parts per million (ppm), to parts per billion (ppb). The combination of variety and trace levels make measurement of the priority pollutants an analytical challenge, the sampling and analysis rife with problems, and the costs high.

Metro contracted with Acurex Corporation of Mountain View, California, for the analytical work of the Toxicant Inventory project. Samples were shipped in Acurex's "Pak-10 kit" containers by air express and preserved or extracted according to EPA-approved protocol within 48 hours of sample collection.

Asbestos, a fibrous material, was not analyzed in this project.

- Inorganic Analysis: Atomic absorption spectroscopy (AAS) was used in the Toxicant Inventory for analysis of water and sediment sampled for the 13 priority pollutant inorganics (as recommended by U.S. EPA, 1979a). Most of the metals (Sb, As, Be, Cd, Cr, Cu, Pb, Ni, Se, Ag and Tl) were atomized by graphite furnace (see below) to ensure low detection limits. Zinc (Zn) was most often atomized by the standard flame technique as levels generally precluded use of the furnace. Mercury (Hg) was handled by the standard cold vapor technique.

  With the graphite furnace, the atoms in the sample are vaporized in a graphite tube furnace rather than in a flame, which is less sensitive. The amount of element in the vapor is detected by a spectroscopic measurement. This measures the amount of selective absorption of a standard wavelength of light radiation by the element of concern.

  Two types of metal values are often reported in the literature based upon extraction techniques before AAS analysis: "total" and "total recoverable." As defined in U.S. EPA (1979a), a total metal value is the result of either a vigorous hot acid digestion of an unfiltered sample or the sum of determinations of dissolved and suspended fractions of a sample. A total recoverable metal value is the result of a "moderate" acid digestion of an unfiltered sample. In the Toxicant Inventory, values are listed as total metals, by hot nitric acid digestion.

  Much variation can exist between different metal values reported from different analyses depending on the type and temperature of acid used, the duration of digestion, and the equipment used. Such important differences are often not reported with the data in the literature. Another point of variation in sediment analyses concerns concentrations as a portion of wet versus dry weight of sample. While most sediment values are reported as dry weight, the analyses in this study are wet weight. Unfortunately, a total solids value needed to compute conversions for comparisons with dry weight data was not obtained. Some conversions from related data were made.

  Detection limits for the Toxicant Inventory metals analyses are listed in Table 5; they were generally around one part per billion (ppb) for the water samples and 100 ppb for sediments.

  Quality assurance and quality control (QA/QC) for the metals followed standard practices (U.S. EPA, 1979b), including duplicate sample analyses, spiked samples, field blanks and lab blanks. Details of the metal QA/QC program and results are provided in Appendix A.

- Cyanide Analysis: The cyanides are a diverse group of compounds varying in character and toxicity but all containing the cyanide ion (CN-). Analysis is problematical because of the variations in solubility, reactivity, volatility, etc. Standard colorimetric analytical methods as published in U.S. EPA (1979a) were used.

  The detection limit for total cyanide was ten ppb. QA/AC followed standard procedures; results are presented in Appendix A.

- Organic (Hydrocarbon) Analysis: The 111 organic priority pollutants are relatively low molecular weight (less than 700) volatile and semi-volatile substances. They range from single carbon compounds, such as chloroform, to multi-ring compounds, such as benzo(a)pyrene ($C_{20}H_{12}$).

  The gas chromatograph (GC) is one of the basic analytical tools for determining trace levels of organic compounds in environmental samples. The GC separates different chemicals present in a solvent extract by vaporizing the extract sample as it passes through a packed glass or capillary column. Various types of detectors such as electron capture (ECD), flame ionization (FID), and mass spectrometer (MS) are used to quantify substances as they emerge from the column.

  The Mass Spectrometer (MS) is one of the most sensitive and versatile of the organic compound detectors. The MS breaks compounds into pieces (ions) by bombarding them with electrons. It then sorts the pieces by their mass-to-charge ratios. The resultant mass spectrum provides a "fingerprint" to identify compounds by comparison with known spectra in a reference library.

  The combination of gas chromatography with mass spectrometry and a computerized data system (commonly abbreviated GC/MS/-DS or just GC/MS) allows analysis -- identification and quantification -- at trace (one to ten ppb) levels of a wide variety of organic compounds in single samples. Since it is such a new, sensitive and complex tool, problems with sample extraction techniques, contamination, reproducibility of results, and interlaboratory calibration are widespread. Very thorough quality assurance and quality control procedures are essential.

  In the Toxicant Inventory, GC/MS was used for all organic analyses using U.S. EPA (1979c) methodologies: #624 for purgeable (volatile) substances and #625 for extractable (semi-volatile) substances. Method #624 uses a standard purge-and-trap technique whereby volatile organic compounds are purged from the sample with an inert gas, trapped on a sorbent material, and then desorbed into the GC. Method #625 extracts less volatile compounds with an organic solvent which is then concentrated and injected into the GC. Two modifications were made in the GC/MS protocols part way through the project. Beginning with sample #22, a capillary column was used in place of a packed column in an attempt to increase sensitivities. At the same time, the acid fraction and base/neutral fraction, isolated from each sample, were combined to decrease instrument run times without compromising results.

Sediment samples were extracted and analyzed as above, after the samples were first made into an aqueous solution with a small volume of deionized distilled water. Desorbing organic compounds from sediment particles is a complex and, at best, only partially successful process.

In order to obtain greater sensitivity (part per trillion range) for the chlorinated pesticides and PCBs (but without confirmation of identities), method #608 by the EPA (1979c) for GC/ECD was used. Extraction proceeded as in method #629, using a Soxhlet apparatus followed by Florisil® clean-up when necessary.

Ten samples were subjected to special survey analyses during the GC/MS runs. For each sample, all major spectrogram peaks (not just those of the priority pollutants) were compared with over 30,000 compounds' spectra in the data system library. The results of those surveys are presented in Section III of this report.

Detection limits for the organic analyses vary with the method or fraction. The volatile analyses (by method #624) generally yield a detection limit between one and ten ppb. Detection limits for the extractable analyses (by method #625) are especially compound-dependent and can vary from one to 50 ppb. Analyses by method #608 yield sub-ppb detection limits (see Table 6 from U.S. EPA, 1979c; for details of method #624 and #625's detection limits, see U.S. EPA, 1980c).

Quality assurance and quality control for the organic analyses followed rigorous EPA procedures (U.S. EPA 1979c and 1980d). These include continuous monitoring for contamination in field sampling, container and laboratory glassware, instrumentation and sample handling, as well as analytical protocol checks using method standards, surrogate compounds spiked into samples, and replicate sample analyses. Details of the organic quality assurance and quality control program and their results are provided in Appendix A of this report.

Following the convention of R. F. Christman (1982), all GC/MS identifications in this report are "confident structural assignments" and many are "confirmed structural assignments."

Table 4. SUMMARY OF METRO'S TOXICANT INVENTORY SAMPLES BY CATEGORY, TYPE, LOCATION, AND NUMBER

Category	Type	Location	Number
Runoff:	stormwater composites	Bellevue-residential (Lake Hills & Surrey Downs)	19
Potential sources:	street dust	Bellevue-residential	10
		Seattle-CBD	2
		Seattle-industrial	2
	atmospheric suspended particles	Seattle-industrial	2
	catchbasin sediments	Bellevue-residential	1
	stormdrain baseflows	Bellevue-residential	2
Receiving waters:	interstitial streamwater	Kelsey & Bear Creeks	5
	stream sediments	Kelsey, Bear, Juanita, & Thornton Creeks	16
	lake sediments	Lake Washington	12

Table 5. DETECTION LIMITS FOR PRIORITY POLLUTANT METALS IN WATER SAMPLES

(Based on Metro-Acurex Contract Specifications)

Element	Detection Limit in ppb[a]
Antimony (Sb)	3
Arsenic (As)	1
Beryllium (Be)	0.2
Cadmium (Cd)	0.2
Chromium (Cr)	5
Copper (Cu)	1
Lead (Pb)	1
Mercury (Hg)	0.2[b]
Nickel (Ni)	1
Selenium (Se)	2
Silver (Ag)	0.2
Thallium (Tl)	1
Zinc (Zn)	0.1

[a] Graphite furnace AAS.

[b] Cold vapor AAS.

Table 6. PESTICIDE AND PCB DETECTION LIMITS BY USEPA METHOD #608 (GC/ECD) (U.S. EPA, 1979c)

Compound	Detection Limit (pptr)[a]
aldrin	3
α-BHC	2
β-BHC	4
λ-BHC	2
δ-BHC	4
chlordane	40
4,4'-DDD	12
4,4'-DDE	6
4,4'-DDT	16
dieldrin	6
endosulfan I	5
endosulfan II	10
endosulfan sulfate	30
endrin	9
endrin aldehyde	23
heptachlor	2
heptachlor epoxide	4
toxaphene	400
PCB-1016	40
PCB-1221	100
PCB-1232	100
PCB-1242	50
PCB-1248	80
PCB-1254	80
PCB-1260	150

[a] pptr = parts per trillion = ng/l or ng/kg.

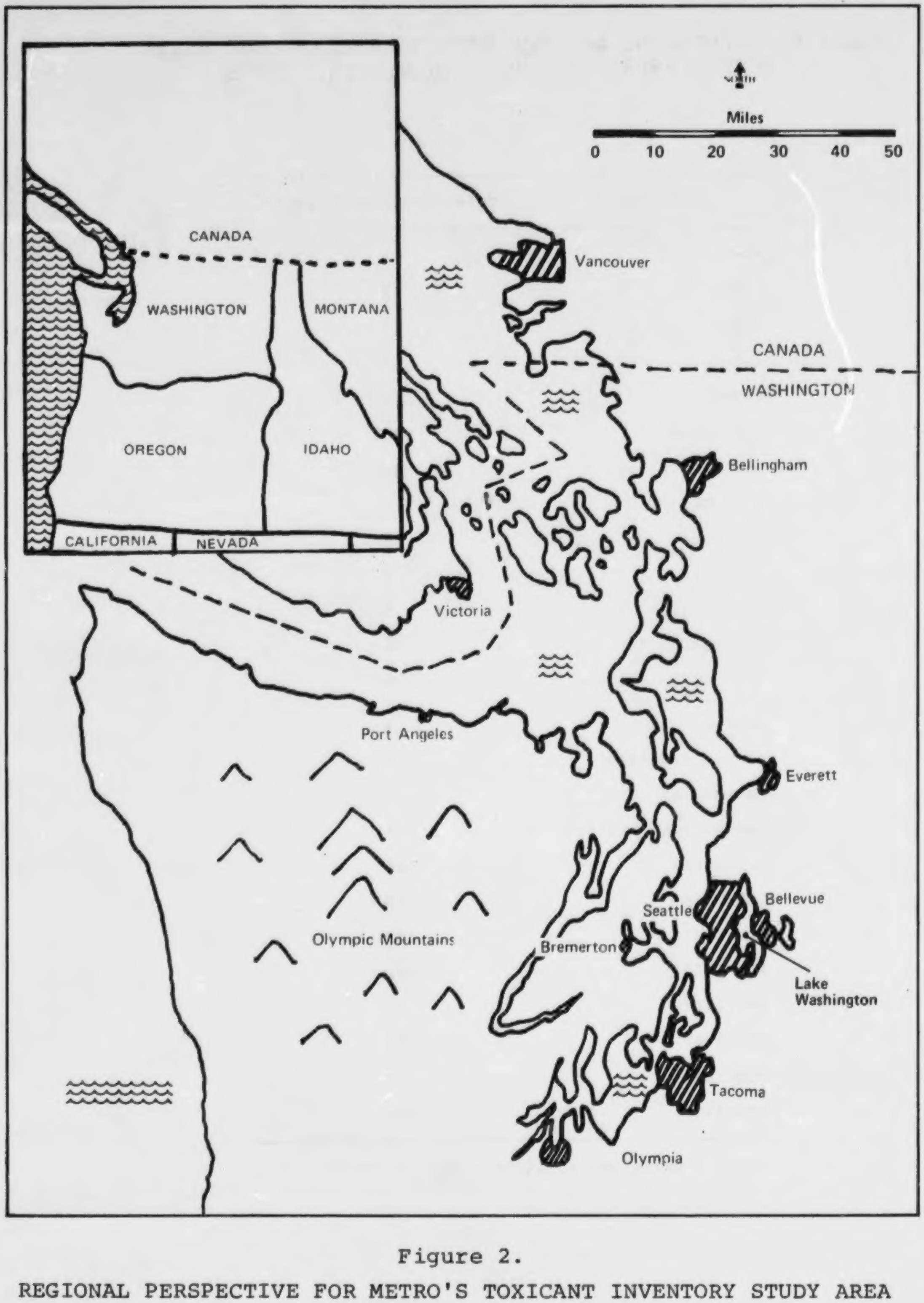
Miles
0
10
20
30
40
50
CANADA
WASHINGTON
MONTANA
OREGON
IDAHO
CALIFORNIA
NEVADA
Vancouver
CANADA
WASHINGTON
Bellingham
Victoria
Port Angeles
Everett
Olympic Mountains
Seattle
Bellevue
Bremerton
Lake Washington
Tacoma
Olympia

Figure 2.
REGIONAL PERSPECTIVE FOR METRO'S TOXICANT INVENTORY STUDY AREA

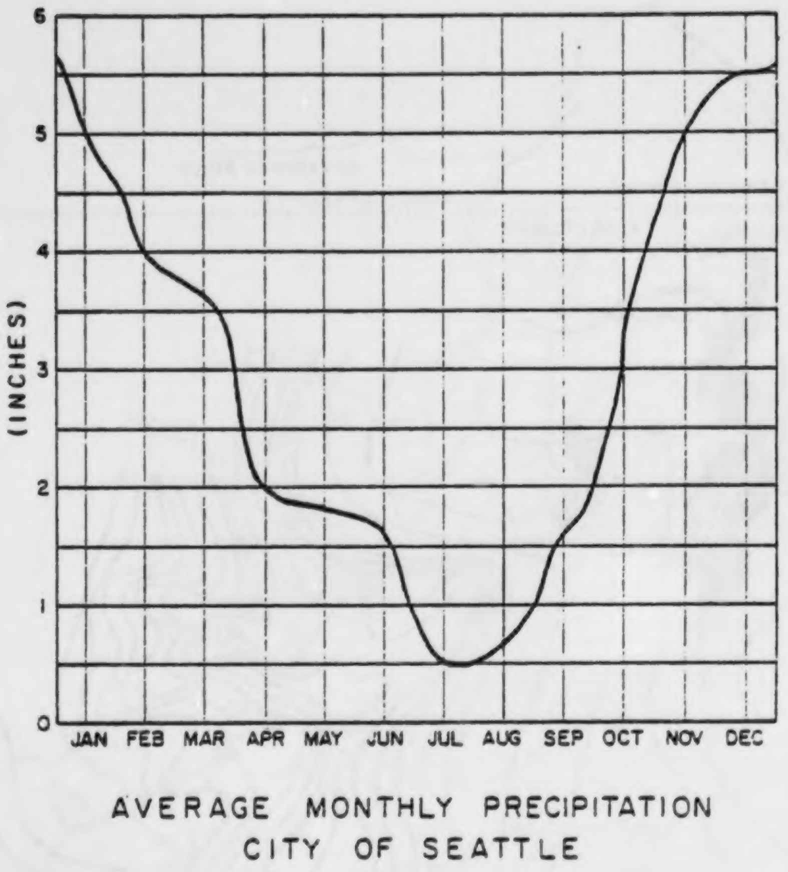

Figure 3.
AVERAGE MONTHLY PRECIPITATION
(Farris et al., 1979)

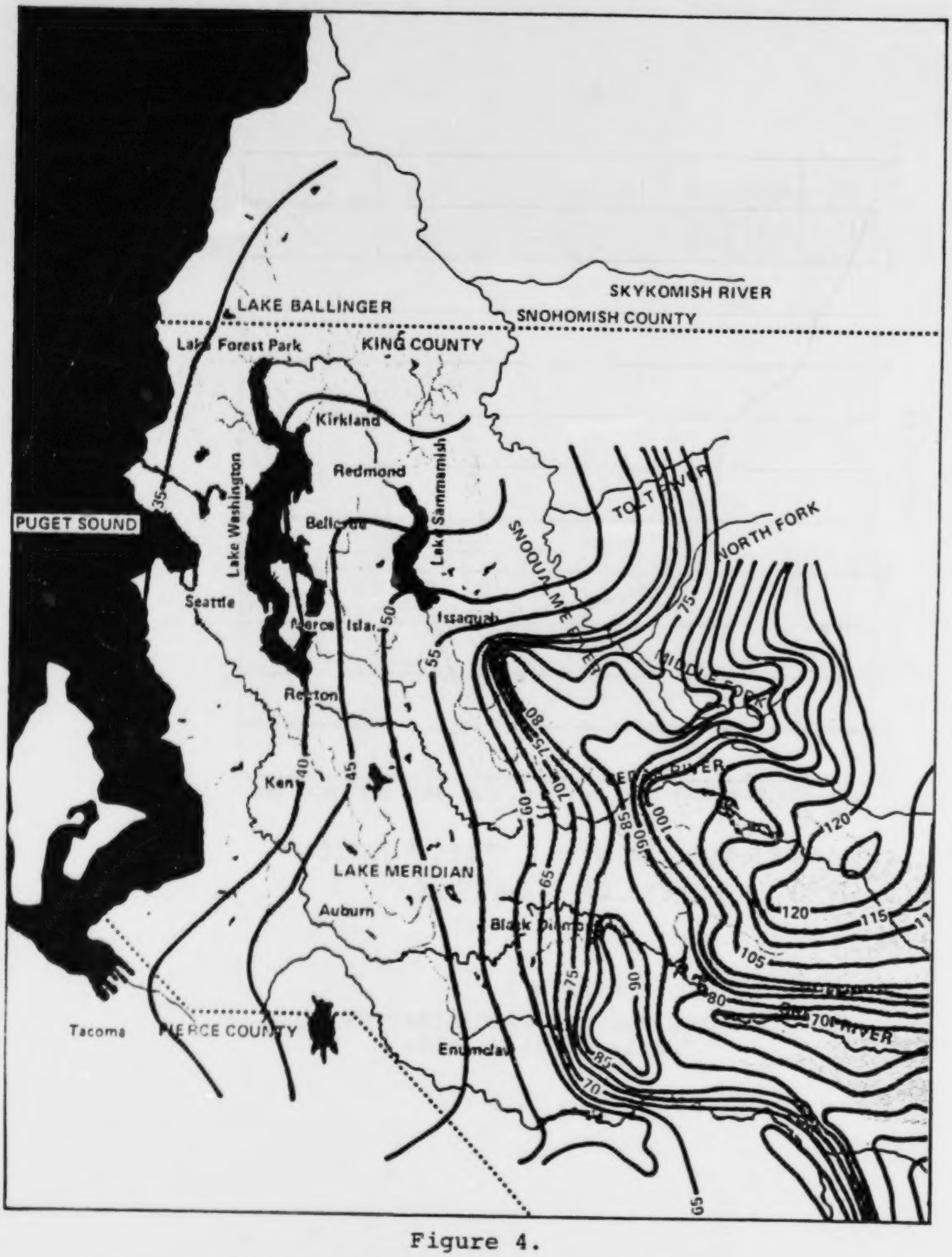
SKYKOMISH RIVER
LAKE BALLINGER
SNOHOMISH COUNTY
Lake Forest Park
KING COUNTY
Kirkland
Redmond
Lake Washington
Lake Sammamish
PUGET SOUND
Bellevue
TOLT RIVER
NORTH FORK
SNOQUALMIE RIVER
Seattle
Issaquah
Mercer Island
MIDDLE FORK
Renton
CEDAR RIVER
Kent
LAKE MERIDIAN
Auburn
Black Diamond
Tacoma
PIERCE COUNTY
Enumclaw
RIVER
35
40
45
50
55
60
65
70
75
80
85
90
100
105
115
120

Figure 4.

ISOHYETAL MAP OF ANNUAL PRECIPITATION
(Davis et al., 1978)

Values are in inches.

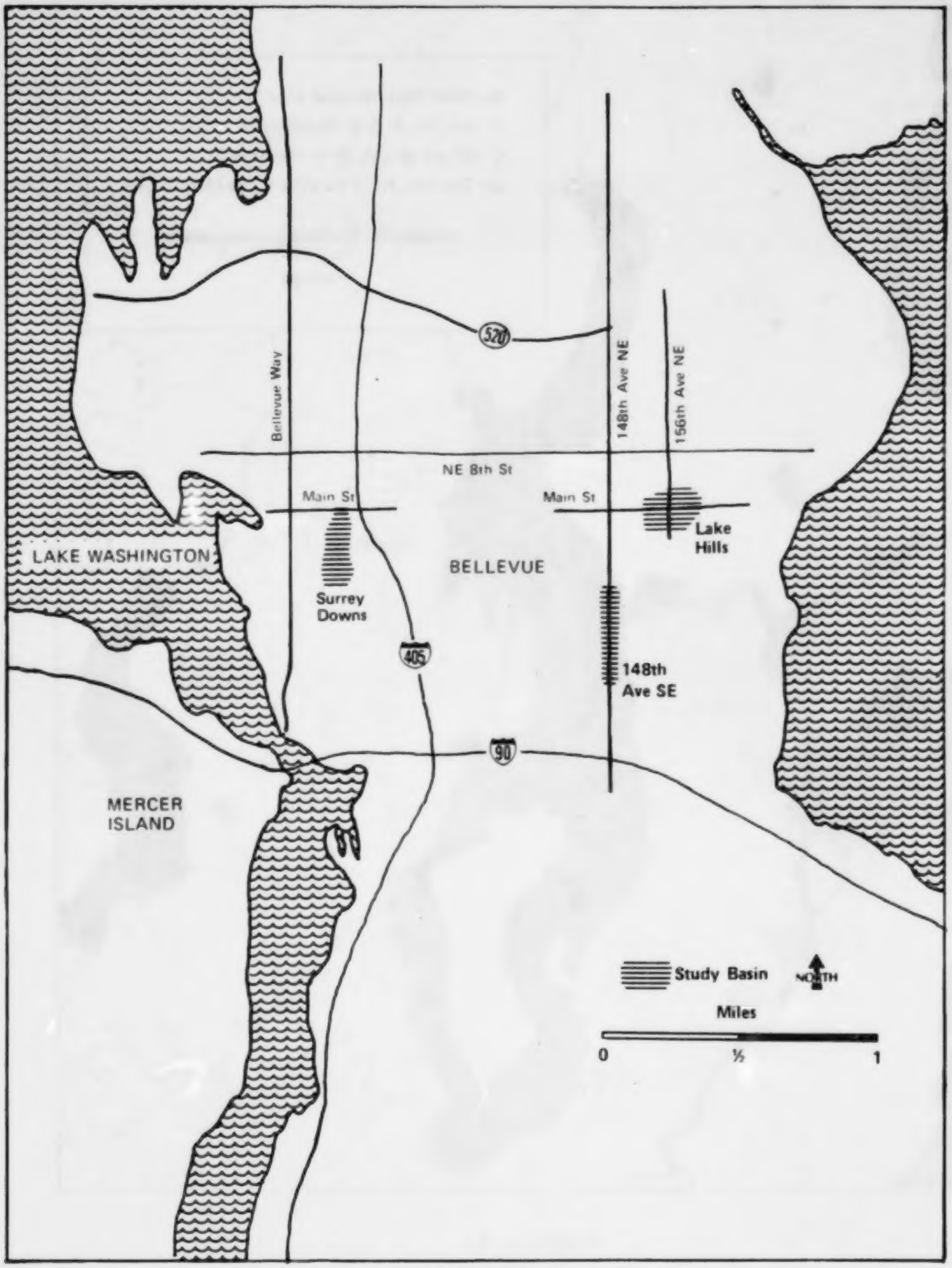
520
Bellevue Way
148th Ave NE
156th Ave NE
NE 8th St
Main St
Main St
Lake Hills
LAKE WASHINGTON
Surrey Downs
BELLEVUE
148th Ave SE
405
90
MERCER ISLAND
Study Basin
NORTH
Miles
0
½
1

Figure 5.

BELLEVUE URBAN RUNOFF PROJECT'S STUDY SITES

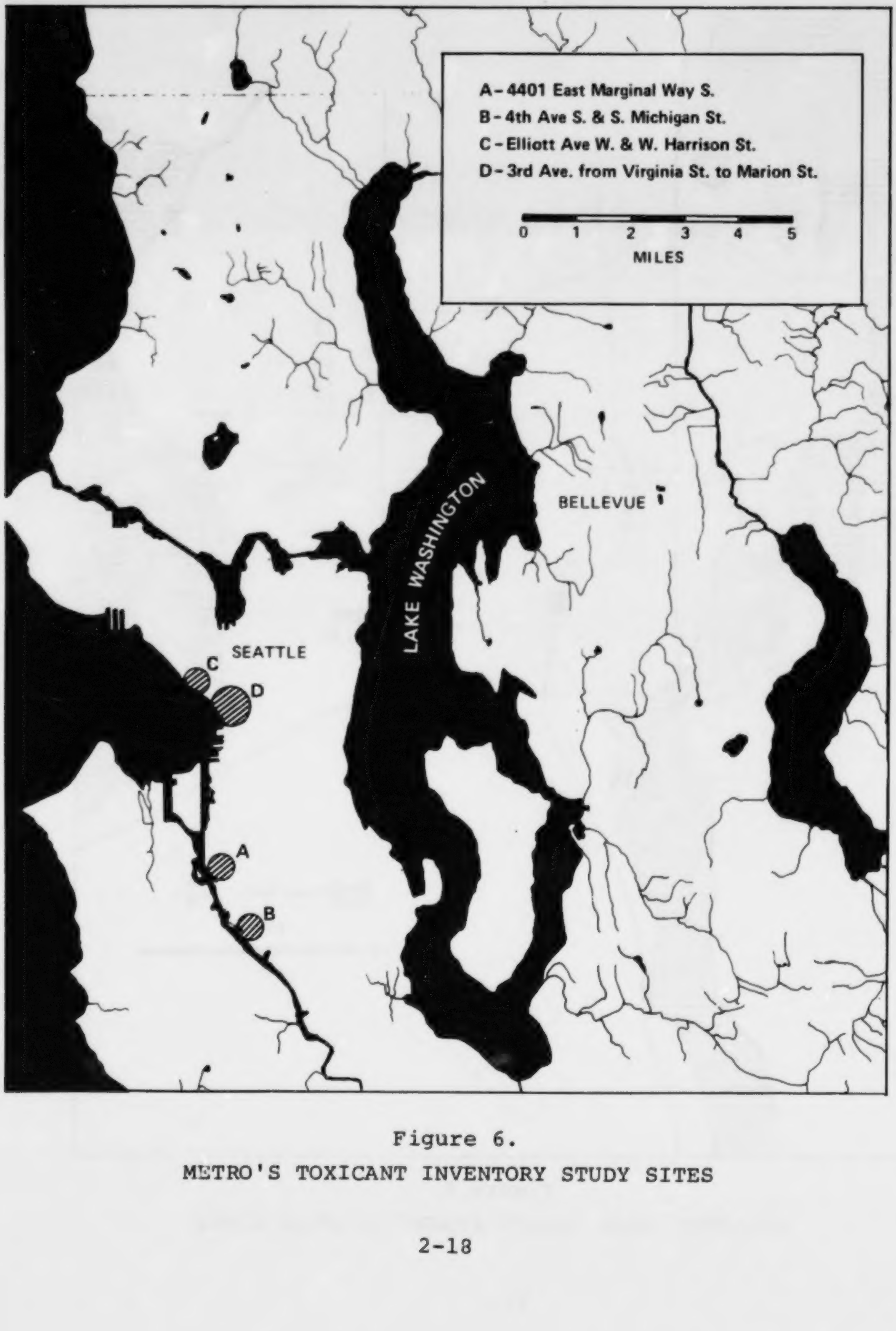
A - 4401 East Marginal Way S.
B - 4th Ave S. & S. Michigan St.
C - Elliott Ave W. & W. Harrison St.
D - 3rd Ave. from Virginia St. to Marion St.
0 1 2 3 4 5
MILES
LAKE WASHINGTON
BELLEVUE
SEATTLE
C
D
A
B

Figure 6.
METRO'S TOXICANT INVENTORY STUDY SITES

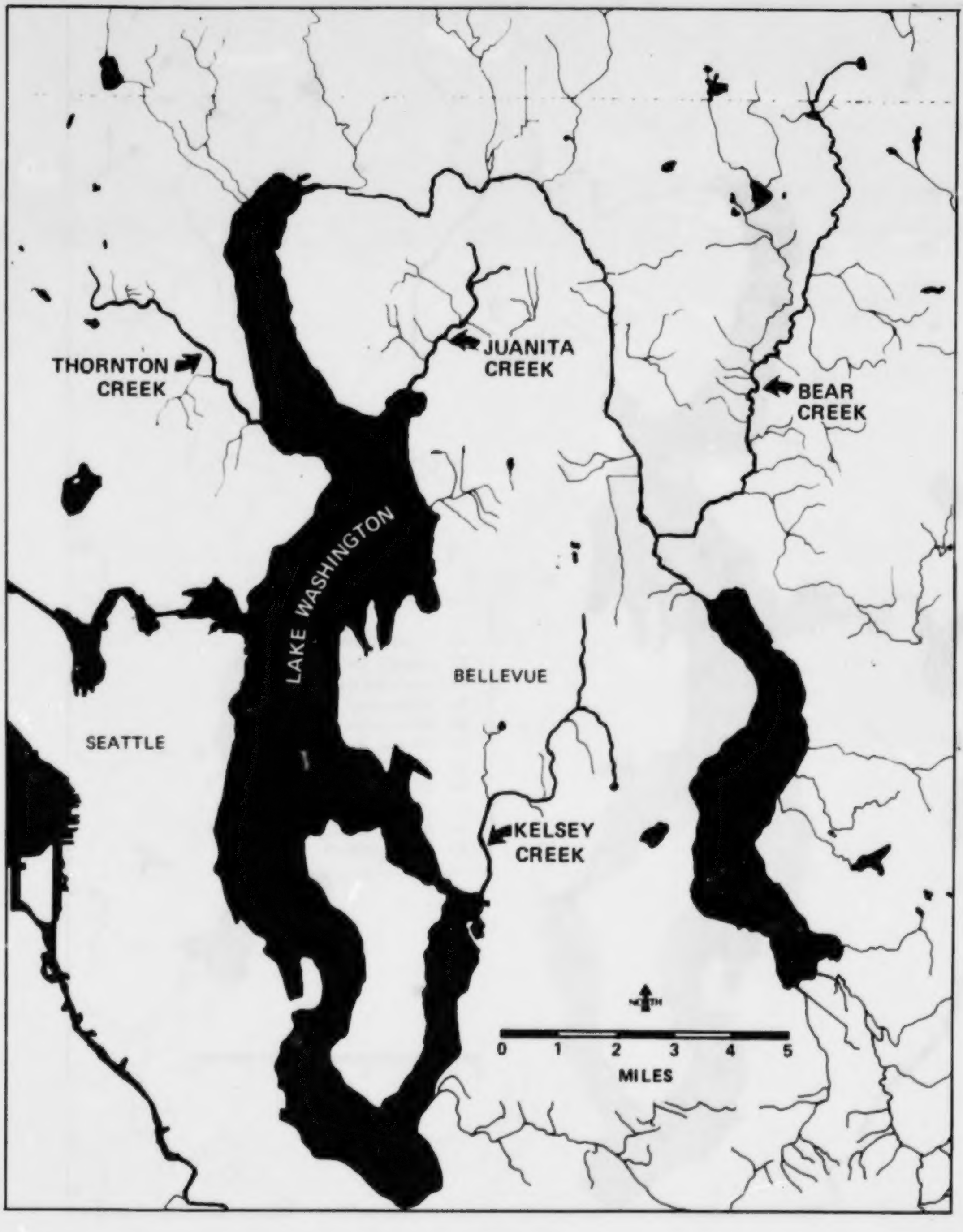
THORNTON CREEK
JUANITA CREEK
BEAR CREEK
LAKE WASHINGTON
BELLEVUE
SEATTLE
KELSEY CREEK
NORTH
0
1
2
3
4
5
MILES

Figure 7.
STREAM SAMPLING SITES

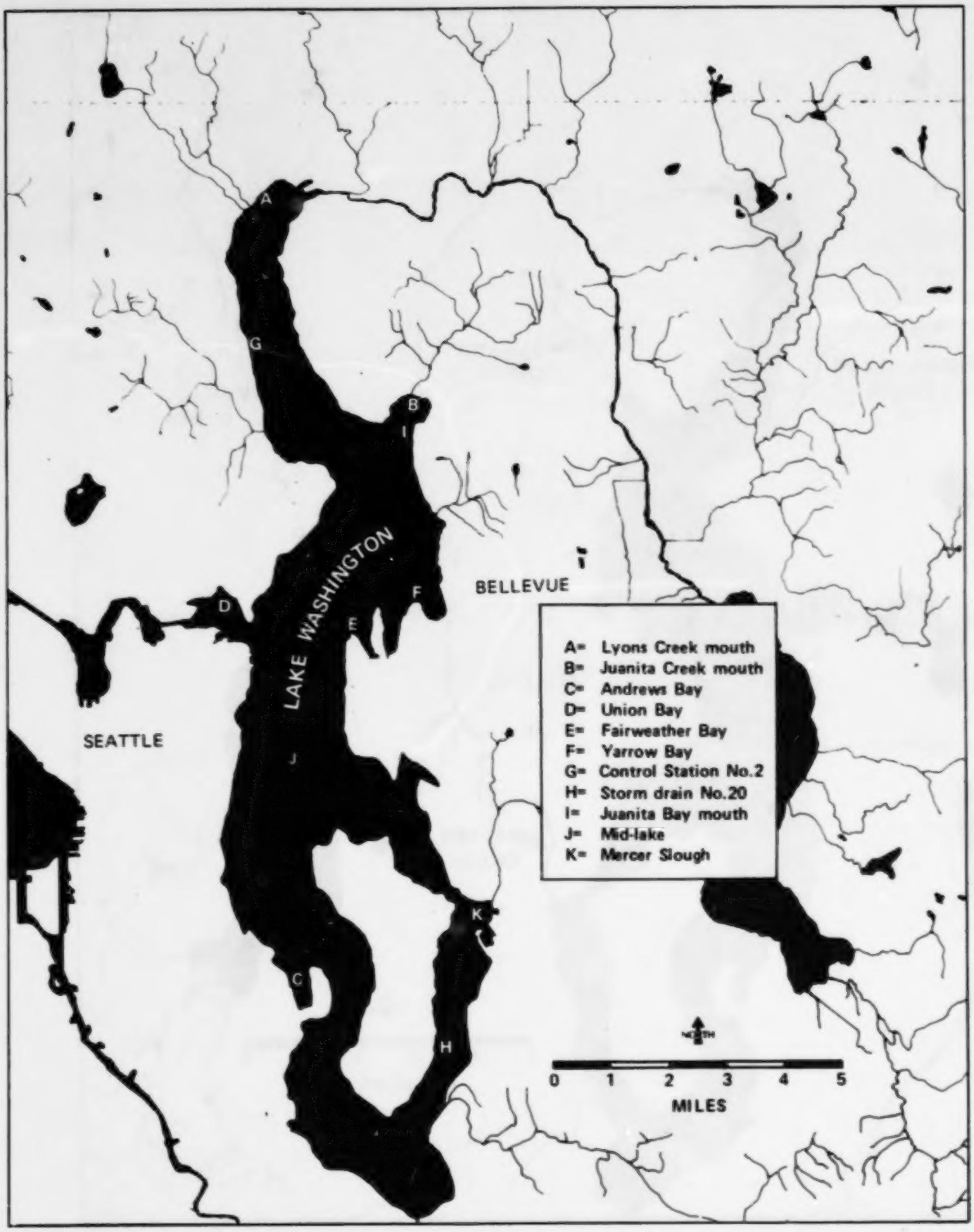
A
G
B
I
LAKE WASHINGTON
BELLEVUE
D
E
F
SEATTLE
J
K
C
H
A= Lyons Creek mouth
B= Juanita Creek mouth
C= Andrews Bay
D= Union Bay
E= Fairweather Bay
F= Yarrow Bay
G= Control Station No.2
H= Storm drain No.20
I= Juanita Bay mouth
J= Mid-lake
K= Mercer Slough
NORTH
0
1
2
3
4
5
MILES

Figure 8.
LAKE WASHINGTON SAMPLING SITES

SECTION III

RESULTS

The following section presents the results of the Toxicant Inventory. These results include data from Metro's field sample analyses, comparable data from other Metro and NURP studies, and relevant data from a general literature review. The presentation of findings begins with an examination of priority pollutant concentrations in stormwater runoff (first inorganics, then organics). Next, general potential sources to runoff are examined (the term source also indicates those environmental areas such as air and soil where nonpoint pollutants tend to collect and concentrate). Following is an examination of receiving waters and their sediments for priority pollutants at concentrations above natural background levels. Finally, a review of studies on currently employed control measures describes their potential uses and limitations for the reduction of toxicants in stormwater.

Each subsection is preceded by a brief summary of the local, NURP, and literature data. The tables and figures referred to in the text are grouped at the end of each subsection.

The outline of this section is as follows:

A. STORMWATER RUNOFF FINDINGS

1. The Metals

2. The Organic Compounds

B. SOURCES OF TOXICANTS TO RUNOFF

1. Street Dust

(a) The Metals.

(b) The Organics.

2. Atmospheric Suspended Particles

(a) The Metals.

(b) The Organics.

3. Catchbasin Sediments and Base Flows

4. Other Significant Sources Cited in the Literature

(a) Urban Soils.

(b) Petroleum from Motor Vehicles.

(c) Atmospheric Wet Precipitation.

(d) Road Surfacing Materials.

(e) Miscellaneous.

C. TOXICANTS IN THE RECEIVING ENVIRONMENT

1. Interstitial Streamwater Sampling
2. Stream Sediments
3. Lake Sediments

D. CONTROL MEASURES AS BEST MANAGEMENT PRACTICES

1. Street Sweeping
2. Detention Basins
3. Retention or Infiltration Basins
4. Wetlands and Grassy Swales
5. Oil and Grease Separators

A. STORMWATER RUNOFF FINDINGS

1. The Metals

(Tables and figures for this subsection begin on page 3-8.)

SUMMARY

- The following six metals were detected in 100% of the Metro stormwater samples: arsenic, cadmium, chromium, copper, lead, and zinc; nickel was detected in 57% of our samples, while all other metals were well below 50%.

- No statistically significant difference was seen between stormwater metal concentrations from swept and unswept basins in the test of streetsweeping as a best management practice.

- Average stormwater concentrations for the following metals exceed chronic water quality criteria: cadmium, copper, lead, nickel, and zinc (reader should be sure to note limitation of the water quality criteria in the Discussion and Analysis section).

- The variability of analytical techniques and detection thresholds in the many cited studies limits meaningful comparisons between data.

- Analyses of total versus dissolved fractions indicate that metals are almost completely associated with stormwater particles; only copper and zinc showed any significant dissolved concentrations.

- Due to a number of variables including climate and landuse differences, stormwater metal concentrations differ tremendously between sampling sites across the country; generally (except for arsenic), the Metro study area was among the lowest.

- Again due to numerous variables, stormwater metal concentrations don't appear to be statistically different between the three basic urban landuse types -- residential, commercial, and industrial. (Runoff from freeway corridors, however, is consistently higher for most metals).

Stormwater runoff data for priority pollutant metals were derived from 21 (19 + two replicate) flow-proportioned composite samples

-- ten from Surrey Downs and 11 from Lake Hills -- taken between October, 1980, and January, 1982. Table 7 presents the runoff data for Surrey Downs and Table 8 for Lake Hills, while Table 9 summarizes all runoff data combined. Sampling equipment blanks using deionized distilled water were included to check for possible sampler contamination (see Appendix A). In addition, one sample from each basin was split and sent as a replicate as part of the Quality Assurance/Quality Control Program.

(a) Occurrence. Tables 7 through 9 show that five of the toxic metals -- antimony, beryllium, mercury, selenium, and thallium -- never appeared above detection limits in any of the samples. The cyanides and silver were detected in less than 10% of the samples and with concentrations at or near detection limits. Nickel was detected in 12 of 21 samples (57%). The remaining six -- arsenic, cadmium, chromium, copper, lead, and zinc -- appeared in 100% of the stormwater samples.

Loadings, as a measure of total contribution of a pollutant to the receiving environment, were calculated from the data in Tables 7 and 8 using flow measurements for each storm and area of the basins. Results, in units of pounds per acre (per storm event) are presented in Tables 10 through 12.

Comparisons between basins, using a difference-between-means (Student's T-test) analysis, show no significant differences (at $p = 0.05$) for any of the metals, either in concentration or loading, as shown in Tables 9 and 12. Similar comparisons between runoff from swept basins and runoff from unswept basins, also shown in Tables 9 and 12, reveal the same result: no significant differences exist for any metals.

(b) Comparison With Criteria. Metal concentrations can be compared with the water quality criteria (U.S. EPA, 1980a) as a first indication of the significance of concentrations seen in runoff samples. Table 9 presents these criteria next to the summary runoff statistics. The chronic criteria (freshwater and saltwater) are 24-hour average concentration limits believed safe for aquatic life. Cadmium and lead values exceeded the freshwater chronic limits and copper its saltwater chronic limit in each of the 21 samples (100%); copper exceeded its freshwater limit 18 of 21 times (86%) and its saltwater chronic limit 15 of 21 times (71%); while nickel exceeded its saltwater chronic limit 9 of 21 times (43%) and its freshwater limit just one of 21 times (5%). Four of these metals also exceeded their acute freshwater or saltwater toxicity criteria, which are values "not to be exceeded at any time" for protection of freshwater organisms. Lead exceeded its acute freshwater limit in each of the 21 samples (100%); copper its freshwater acute value in 19 of 21 samples (90%) and its saltwater acute value in 8 of 21 samples (38%); cadmium and zinc exceeded their freshwater acute values in 10 of 21 samples (48%); and zinc exceeded its saltwater acute value in 6 of 21 samples (29%).

When criteria required calculations using average freshwater hardness values, 20 mg/l of $CaCO_3$ was used, reflecting the region's very soft water. It should be kept in mind that these criteria values are for ambient receiving water concentrations and not undiluted stormwater. In addition, the runoff concentrations are composites of each storm event and may not persist for the full 24-hour period required for chronic evaluations, nor reflect single higher peaks during the storm event required for acute evaluations.

(c) Comparison With Other NURP Data. Nineteen of the NURP projects have collected some data on priority pollutants in runoff, although none as extensively as Bellevue has through this Toxicant Inventory. Preliminary data from these projects (U.S. EPA, 1982c), while not complete at the time of this writing, provide a number of points of comparison with Metro's findings.

Figure 9 compares the occurrence of priority pollutant metals in Metro's stormwater samples with those of all NURP cities (including the Metro Bellevue data). Of the inorganics analyzed for in urban runoff, only thallium was undetected by all the NURP cities, and only zinc was seen at detectable concentrations in every sample. Lead was found in 93% of the samples, copper in 91%, and arsenic in 58%. The rest of the metals and the cyanides appeared in less than 50% of the stormwater samples. The generally lower occurrences reported by the other NURP studies suggest that their analytical techniques resulted in higher detection limits than the analytical methods used in Metro's study (see Experimental Design section).

A comparison of other NURP stormwater concentrations with chronic freshwater criteria reveals the following: cadmium, copper, and lead exceeded in 100%, cyanides in 90%, zinc in 89%, and nickel in 40% of their occurrences. For the acute freshwater criteria, NURP data show that detectable values for copper exceeded toxic limits in 76% of their occurrences, cadmium in 53%, lead in 40% and zinc in 13% (see Figure 10). For criteria requiring an average water hardness value, NURP used 100 mg/l of $CaCO_3$.

In conjunction with NURP, EPA's Monitoring and Data Support Division conducted a "special metals" study to determine dissolved versus total concentrations for the metals in runoff. Composite samples were collected from 25 NURP projects, split, half-passed through a 0.45 micron filter (defined as dissolved or soluble), and analyzed by Inductively-Coupled Plasma (ICP) Atomic Emission Spectrometry. Table 13 presents the preliminary results from the first 109 samples. The relatively high detection limits of ICP prevented collection of much usable data, especially in the dissolved fraction. The preliminary results indicate that only two priority pollutant metals, copper and zinc, were present in dissolved forms (as much as 40%) to any appreciable extent.

(d) Comparison With the Literature. Much information on metals in runoff exists in the literature, and the published data show a high degree of variability in concentrations, loadings, etc. Certain metals (e.g., lead, zinc, copper, chromium) have consistently been reported in runoff and have been the focus of concern because of their potential toxicities. The mean concentrations for metals data from four representative urban stormwater runoff studies are compared with Metro values in Table 14. For each reported metal, Metro generally had the lowest stormwater concentration averages.

The Metro report entitled Urban Drainage Stormwater Monitoring Program (Farris et al., 1979) presents results of a study of three stormwater sampling sites in the Seattle area: a single-family residential area (View Ridge), a commercial shopping center (Southcenter), and a light manufacturing area (South Seattle). Table 15 displays mean values for cadmium, lead, and zinc concentrations and compares them with the mean values from this study. It can be seen that the average stormwater concentrations from the Bellevue residential basins are generally lower than the various Seattle basins. The differences are not significant (at $p = 0.05$) between the two residential lead and zinc values, or between the residential and industrial lead, or commercial and industrial zinc. The stormwater metal values all exceed both acute and chronic freshwater toxicity criteria.

An earlier Metro study of freeway runoff from I-90 (Farris et al., 1973) analyzed both soluble (filtrate passed through a 1.2 micron filter) and insoluble (associated with particulates on the filter) fractions of the runoff. Table 16 presents these data for five metals. Chui et al. (1981), in the recent University of Washington study of highway runoff in Washington state, found lower values for lead and copper than Farris et al. (1973) but higher values for zinc coming from two I-5 sites in Seattle. Table 17 presents a summary of their data. Both studies found much higher metal concentrations in freeway runoff than are seen in other local landuse types. The variability in the data should also be noted.

In one of the only other local references available on inorganic toxicant concentrations in runoff, Crecelius (1975) reported arsenic concentrations in stormwater runoff from stormdrains on the west side of Lake Washington averaging 15 ppb, very similar to concentrations found in the Metro runoff samples.

Association of metals with particles in the runoff is addressed in detail in the presentation of street dust information to follow.

The loading rate is an important measure of total contribution of a pollutant to the receiving environment. Loadings, however, are calculated using a variety of methods and the literature contains a myriad of different and generally non-compatible units such as lbs/acre (per average storm event), lbs/acre/year, lbs/curb mile, and lbs/acre/inches of rainfall. Table 18 presents the local loading rates for different landuse types developed by Farris et al. (1979), which are given as lbs/acre/storm event. Table 19 presents loadings from Sartor and Boyd (1972) for national averages and Seattle only, as lbs/curb mile averaged for all landuse types. In their review of available literature, Rolan et al. (N.D.) show a range of loading rates (in kg/ha/year) of 0.04 - 9.3 for lead, 0.11 - 2.7 for zinc, 0.01 - 1.8 for chromium, 0.02 - 1.3 for copper, and 0.001 - 0.03 for cadmium. Although they found a very general trend in landuse loadings (highest from industrial areas to lowest from residential), they concluded that usefulness of the highly variable, national loading data was "limited."

Table 7. CONCENTRATIONS OF METALS IN STORMWATER RUNOFF--SURREY DOWNS (Metro Toxicant Inventory Data)

All values are concentrations in ppb or μg/l. "Less than" (<) values represent detection limits.

	DETECTION OCCURRENCE	#15: Surrey Downs, 30 OCT '80	#21: Surrey Downs, 24 FEB '81	#22: Surrey Downs, 30 JUN '81	#22: Surrey Downs-REPLICATE	#41: Surrey Downs, 19 SEPT '81	#43: Surrey Downs, 27 OCT '81	#51-A: Surrey Downs, 10 JUL '81	#51-C: Surrey Downs, 28 OCT '81 (swept)	#51-E: Surrey Downs, 11 JAN '82	#51-G: Surrey Downs, 16 JAN '82	Mean Concentration	Standard Deviation (SD)
Antimony	0/10	<2	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	--
Arsenic	10/10	4	4	33	37	30	4	9	3	27	5	16	(±14)
Beryllium	0/10	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	--
Cadmium	10/10	0.3	0.2	1.3	1.3	0.9	0.3	0.4	0.3	0.8	0.5	0.6	(± 0.4)
Chromium	10/10	2	2	9	10	17	3	8	3	19	8	8	(± 6)
Copper	9/9	12	11	46	46	32	10	19	(9)[a]	21	5	(22)	(±15)
Lead	10/10	70	66	460	430	450	72	200	70	420	94	230	(±180)
Mercury	0/9	<1	<0.5	(0.5)[b]	<0.5	<1	<0.5	<0.5	<0.5	<0.5	<0.5	<1	--
Nickel	6/10	(<9)	(<10)	20	20	12	5	32	<3	9	<3	12[c]	(±5[c])
Selenium	0/10	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	--
Silver	1/10	0.6	<1	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<1	--
Thallium	0/10	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	--
Zinc	10/10	60	40	250	230	240	60	130	56[a]	180	71	130	(±86)
Cyanides	1/6	<10	≤10	<5	<5	<5	<10	NA	NA	NA	NA	<10	--

---

[a] Field blank for sample #51C had 11 ppb copper and 10 ppb zinc as contamination (see Appendix A); the copper value is disregarded and the zinc value reduced in determination of mean.

[b] Method blank for sample #22 showed contamination or false positive for mercury at 0.5 ppb; the 0.5 data point is disregarded (see Appendix A).

[c] Estimates of this mean and Sd are based on Aitchison's delta distribution (see Appendix B); samples #15 and #21 were not used in calculation because detection limits were higher than observed values in samples #43 and #51E.

Table 8. CONCENTRATIONS OF METALS IN STORMWATER RUNOFF -- LAKE HILLS

(Metro Toxicant Inventory Data)
All values are concentrations in ppb or µg/l. "Less than" (<) values represent detection limit.

ppb	DETECTION OCCURRENCE	#14: Lake Hills, 31 OCT '80 (swept)	#18: Lake Hills, 21 JAN '81 (swept)	#19: Lake Hills, 11 FEB '81 (swept)	#20: Lake Hills, 24 FEB '81 (swept)	#23: Lake Hills, 30 JUN '81 (swept)	#23: Lake Hills - REPLICATE (swept)	#42: Lake Hills, 27 OCT '81	#51-B: Lake Hills, 13 JUL '81	#51-D: Lake Hills, 28 OCT '81	#51-F: Lake Hills, 11 JAN '82	#51-H: Lake Hills, 16 JAN '82	Mean Concentration	Standard Deviation (SD)
Antimony	0/11	<2	<3	<3	<3	<3	<3	<3	<3	< 3	<3	< 3	<3	--
Arsenic	11/11	4	10	5	4	27	27	2	5	3	19	5	10	(±10)
Beryllium	0/11	0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	< 0.3	< 0.3	< 0.3	<0.3	--
Cadmium	11/11	<0.3	≤0.1	1	0.3	1.2	1.1	0.2	1.9	0.2	0.8	0.6	0.7	(±0.6)
Chromium	11/11	5	14	7	3	10	9	2	3	2	16	4	7	(±5)
Copper	10/10	24	20	25	12	28	28	12	12[a]	(11)[a]	25	4	18	(±9)
Lead	11/11	190	120	260	100	370	370	60	110	60	420	60	190	(±140)
Mercury	0/11	<1	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	< 0.5	< 0.5	< 0.5	<1	--
Nickel	6/11	< 9	5	<10	<10	27	27	3	18	< 3	12	< 3	11[b]	(±8[b])
Selenium	0/11	<2	<2	<2	<2	<2	<2	<2	<2	< 2	< 2	< 2	<2	--
Silver	0/10	≤0.2	≤0.2	<0.2	<1		<0.5	<0.2	<0.2	< 0.2	< 0.2	< 0.2	<1	--
Thallium	0/11	<1	<1	<1	<1	<1	<1	<1	<1	< 1	< 1	< 1	<1	--
Zinc	11/11	110	70	110	60	240	240	50	56	32[a]	120	28	100	(±77)
Cyanides	1/6	<10	20	<10	<10	NA	<5	<10	NA	NA	NA	NA	<20	--

[a] Field blank for sample #51B had 5 ppb copper and for sample #51D had 11 ppb copper and 15 ppb zinc as contamination (see Appendix A); the #51D copper value is disregarded and the #51B copper and #51D zinc values reduced in determination of means.

[b] Estimates of this mean and Sd are based on Aitchison's delta distribution (see Appendix B); samples #14, 19 and 20 were not used.

[c] Method blank for sample #23 showed contamination or false positive for silver at 0.5 ppb; the 0.8 data point is disregarded (see Appendix A).

Table 9. SUMMARY OF METAL CONCENTRATIONS IN STORMWATER RUNOFF (Metro Toxicant Inventory Data)
All mean and median values are concentrations in ppb or μg/l. No significant differences exist between the Surrey Downs and Lake Hills basins or between swept and non-swept treatments.

	Surrey Downs			Lake Hills				Swept (n=7)		Non Swept (n=14)			TOTALS			USEPA (1980a) Water Quality Criteria			
																Fresh-water		Salt-water	
ppb	Occurrence	Mean	SD	Occurrence	Mean	SD	Significant Difference (p=.05)	Mean	SD	Mean	SD	Significant Difference (p=.05)	Occurrence	Mean	SD	Acute	Chronic	Acute	Chronic
Antimony	0/10	--		0/11	--								0/21	--		--	--	--	--
Arsenic	10/10	16	(±14)	11/11	10	(±10)	no	11	(±11)	13	(±13)	no	21/21	13	(±12)	440	--	--	--
Beryllium	0/10	--		0/11	--								0/21	--		--	--	--	--
Cadmium	10/10	0.6	(±.4)	11/11	0.7	(±.6)	no	0.6	(±.5)	0.7	(±.5)	no	21/21	0.7	(±.5)	0.6	.005	59	4.5
Chromium	10/10	8		11/11	7	(±5)	no	7	(±4)	8	(±6)	no	21/21	7	(±5)	(21)[a]	(.29)[a]	1260[a]	(18)[a]
Copper	9/10	22		10/10	18	(±9)	no	21	(±8)	19	(±14)	no	19/19	20	(±12)	5	5.6[b]	23	4.0
Lead	10/10	230		11/11	190	(±140)	no	210	(±120)	210	(±180)	no	21/21	210	(±160)	24	0.09	--	--
Mercury	0/9	--		0/11	--								0/20	--		4.1	0.20	3.7	0.1
Nickel	6/10	12[c]		6/11	11[c]	(±8)	no	9[c]	(±7)	11[c]	(±4)	no	12/21	12[c]	(±4)	540	28	140	7.1
Selenium	0/10	--		0/11	--								0/21	--		260	35	410	54
Silver	1/10	--		0/10	--								1/20	--		0.3	--	2.3	--
Thallium	0/10	--		0/11	--								0/21	--		--	--	--	--
Zinc	10/10	130		11/11	100	(±75)	no	130	(±81)	110	(±82)	no	21/21	120	(±80)	85	47	170	58
Cyanides	1/6	--		1/6	--								2/12	--		52	3.5	--	--

[a] Chromium criteria are for hexavalent chrome (Cr^{+6}), not total chrome.

[b] Acute value derived by formula, chronic value given by EPA.

[c] Estimates of the mean and sd are based on Aitchison's delta distribution (see Appendix B).

Table 10. LOADINGS OF METALS IN STORMWATER RUNOFF-SURREY DOWNS (Metro Toxicant Inventory Data)

All values are loadings in pounds per acre per storm event.
(Conversion = lbs/ac = 1.12 kg/ha.)[a]

lbs/acre	DETECTION OCCURRENCE	#15: Surrey Downs, 31 OCT '80	#21: Surrey Downs, 24 FEB '81	#22: Surrey Downs, 30 JUN '81	#22: Surrey Downs-REPLICATE	#41: Surrey Downs, 19 SEPT '81	#43: Surrey Downs, 27 OCT '81	#51-A: Surrey Downs, 10 JUL '81	#51-C: Surrey Downs, 28 OCT '81 (swept)	#51-E: Surrey Downs, 11 JAN '82	#51-G: Surrey Downs, 16 JAN '82	Mean Loading	Standard Deviation (SD)
Total flow sampled storm (in cu. ft)		48,500	34,300	11,500	11,500	18,800	39,500	6,230	9,170	17,800	90,800		
Antimony	0/10	--	--	--	--	--	--	--	--	--	--	--	--
Arsenic	10/10	.00013	.00010	.00026	.00030	.00039	.00011	.00004	.00001	.00034	.00032	.0020	(±.00014)
Beryllium	0/10	--	--	--	--	--	--	--	--	--	--	--	--
Cadmium	10/10	.00001	.00000	.00001	.00001	.00001	.00001	.00000	.00000	.00001	.00003	.00001	(±.000008)
Chromium	10/10	.00007	.00007	.00008	.00008	.00022	.00008	.00003	.00002	.00024	.00051	.00014	(±.00015)
Copper	9/9	.00041	.00026	.00037	.00037	.00042	.00028	.00008		.00026	.00032	.00031	(±.00010)
Lead	10/10	.00237	.00158	.00368	.00344	.00589	.00198	.00086	.00045	.00521	.00595	.00314	(±.00203)
Mercury	0/9	--	--		--	--	--	--	--	--	--	--	--
Nickel	6/10	--	--	.00016	.00016	.00016	.00014	.00014	--	.00011	--	.00014	(±.00002)
Selenium	0/10	--	--	--	--	--	--	--	--	--	--	--	--
Silver	1/10	.00002	--	--	--	--	--	--	--	--	--	--	--
Thallium	0/10	--	--	--	--	--	--	--	--	--	--	--	--
Zinc	10/10	.00203	.00096	.00200	.00184	.00314	.00165	.00056	.00036	.00221	.00449	.00193	(±.00122)
Cyanides	1/6	--	.00024	--	--	--	--	--	--	--	--	--	--

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[a] Since some of the Metro samples were incomplete storm event composites, these calculations must be considered gross estimates and may be artificially high.

Table 11. LOADINGS OF METALS IN STORMWATER RUNOFF -- LAKE HILLS

(Metro Toxicant Inventory Data)
All values are loadings in pounds per acre per storm event.
(Conversion: lbs/ac = 1.12 kg/ha.)

lbs/acre	DETECTION OCCURRENCE	#14: Lake Hills 31 OCT '80 (swept)	#18: Lake Hills 21 JAN '81 (swept)	#19: Lake Hills 11 FEB '81 (swept)	#20: Lake Hills, 24 FEB '81 (swept)	#23: Lake Hills, 30 JUN '81 (swept)	#23: Lake Hills, REPLICATE (swept)	#42: Lake Hills, 27 OCT '81	#51-B: Lake Hills, 13 JUL '81	#51-D: Lake Hills, 28 OCT '81	#51-F: Lake Hills 11 JAN '82	#51-H: Lake Hills, 16 JAN '82	Mean Loading	Standard Deviation (SD)
Total Flow of sampled storm (in cu. ft.)		33,700	13,700	18,800	13,400	21,900	21,900	36,500	126,000	12,500	25,500	113,000		
Antimony	0/11	--	--	--	--	--	--	--	--	--	--	--	--	--
Arsenic	11/11	.00009	.00009	.00006	.00004	.00001	.00001	.00005	.00041	.00002	.00032	.00037	.00013	(±.00015)
Beryllium	0/11	--	--	--	--	--	--	--	--	--	--	--	--	--
Cadmium	11/11	.00001	.00000	.00001	.00000	.00002	.00002	.00000	.00016	.00000	.00001	.00004	.00002	(±.00005)
Chromium	11/11	.00011	.00013	.00009	.00003	.00014	.00013	.00005	.00025	.00002	.00027	.00030	.00014	(±.00010)
Copper	10/10	.00053	.00018	.00031	.00011	.00040	.00040	.00029	.00099		.00042	.00030	.00039	(±.00024)
Lead	11/11	.00419	.00108	.00320	.00088	.00529	.00539	.00143	.00906	.00049	.00701	.00443	.00276	(±.00276)
Mercury	0/11	--	--	--	--	--	--	--	--	--	--	--	--	--
Nickel	6/11	--	.00004	--	--	.00039	.00039	.00007	.00148	--	.00020	--	.00043	(±.00054)
Selenium	0/11	--	--	--	--	--	--	--	--	--	--	--	--	--
Silver	0/10	--	--	--	--		--	--	--	--	--	--	--	--
Thallium	0/11	--	--	--	--	--	--	--	--	--	--	--	--	--
Zinc	11/11	.00242	.00063	.00135	.00053	.00343	.00343	.00120	.00461	.00026	.00200	.00207	.00199	(±.00139)
Cyanides	1/6	--	.00018	--	--	--	--	--	--	--	--	--	--	--

[a] Since some of the Metro samples were incomplete storm event composites, these calculations must be considered gross estimates and amy be artificially high.

Table 12. SUMMARY OF METAL LOADINGS IN STORMWATER RUNOFF

(Metro Toxicant Inventory Data)

All mean values are loadings in pounds per acre per average storm event.[a]
No significant differences exist between the Surrey Downs and Lake Hills basins or between swept and non-swept treatments.

	Surrey Downs			Lake Hills				Swept		Non Swept			TOTALS		
	Occurrence	Mean Loading	(SD)	Occurrence	Mean Loading	(SD)	Significant Difference (p=.05)	Mean Loading	(SD)	Mean Loading	(SD)	Significant Difference (p=.05)	Occurrence	Mean Loading	(SD)
Antimony	0/10	--	--	0/11	--	--	--	--	--	--	--	--	0/21	--	--
Arsenic	10/10	.0002	(±.0001)	11/11	.0001	(±.0002)	no	.0001	(±.0001)	.0002	(±.0001)	no	21/21	.0002	(±.0001)
Beryllium	0/10	--	--	0/11	--	--	--	--	--	--	--	--	0/21	--	--
Cadmium	10/10	.00001	(±.00001)	11/11	.00002	(±.00005)	no	.00001	(±.00001)	.00002	(±.00004)	no	21/21	.00002	(±.00003)
Chromium	10/10	.0001	(±.0002)	11/11	.0001	(±.0001)	no	.0001	(±.0001)	.0002	(±.0001)	no	21/21	.0001	(±.0001)
Copper	9/9	.0003	(±.0001)	10/10	.0004	(±.0002)	no	.0003	(±.0002)	.0003	(±.0002)	no	19/19	.0003	(±.0002)
Lead	10/10	.0031	(±.0020)	11/11	.0028	(±.0028)	no	.0029	(±.0021)	.0038	(±.0026)	no	21/21	.0035	(±.0024)
Mercury	0/10	--	--	0/11	--	--	--	--	--	--	--	--	0/21	--	--
Nickel	6/10	.0001	(±.0000)	6/11	.0004	(±.0005)	yes	.0003	(±.0002)	.0003	(±.0004)	no	12/21	.0003	(±.0004)
Selenium	0/10	--	--	0/11	--	--	--	--	--	--	--	--	0/21	--	--
Silver	1/10	--	--	0/10	--	--	--	--	--	--	--	--	1/20	--	--
Thallium	1/10	--	--	0/11	--	--	--	--	--	--	--	--	0/21	--	--
Zinc	10/10	.0019	(±.0012)	11/11	.0018	(±.0014)	no	.0017	(±.0013)	.0021	(±.0013)	no	21/21	.0020	(±.0013)
Cyanides	1/6	--	--	1/6	--	--	--	--	--	--	--	--	2/21	--	--

[a] Since some of the Metro samples were incomplete storm event composites, these calculations must be considered gross estimates and may be artificially high.

Table 13. SUMMARY OF NURP SPECIAL METALS RESULTS
These data are from USEPA (1982d) and are incomplete at this time (Healy, pers. comm.)
(Means were calculated using detection limits or 10% of detection limits for the undetected values.)

POLLUTANT	Form	Number of Detected Values	Geometric Mean RMK=0.10RMK*	Geometric Mean RMK=RMK*	Range of Detected Values	Detection Limit
Arsenic	Total	13	1	11	10-130	10
	Total Recoverable	5	-	-	10- 40	10
	Dissolved	1	-	-	10	10
Beryllium	Total	4	-	-	2	2
	Total Recoverable	3	-	-	2	2
	Dissolved	1	-	-	2	2
Cadmium	Total	5	-	-	5	5
	Total Recoverable	4	-	-	5	5
	Dissolved	2	-	-	5-10	5
Chromium	Total	52	4	14	10-110	10
	Total Recoverable	44	3	13	10-100	10
	Dissolved	2	-	-	10- 20	10
Copper	Total	54	10	31	20-520	20
	Total Recoverable	54	10	31	20-520	20
	Dissolved	22	4	24	20-380	20
Lead	Total	69	45	105	40-28,000	40
	Total Recoverable	69	47	107	40-28,700	40
	Dissolved	7	5	46	40- 1,620	40
Mercury	Total	3	-	-	1-5	1
	Total Recoverable**	-	-	-	-	-
	Dissolved	2	-	-	1	1
Nickel***	Total	21	4	23	20-120	20
	Total Recoverable	12	3	22	20-100	20
	Dissolved	2	2	21	20-140	20
Selenium	Total	0	-	-	-	10
	Total Recoverable	0	-	-	-	10
	Dissolved	0	-	-	-	10
Silver	Total	0	-	-	-	10
	Total Recoverable	0	-	-	-	10
	Dissolved	0	-	-	-	10
Thallium	Total	0	-	-	-	10
	Total Recoverable	0	-	-	-	10
	Dissolved	0	-	-	-	10
Zinc	Total	100	102	124	10-5,750	10
	Recoverable	101	113	131	10-5,640	10
	Dissolved	92	37	51	10-2,340	10

*RMK = REMARK and indicates non-detection.
**There were no data for total recoverable mercury.
***Contamination suspected in dissolved fraction.

Table 14. COMPARISON OF METAL CONCENTRATIONS IN STORMWATER FROM SELECTED STUDIES.

Mean concentrations (and, where available, ±standard deviations) are ppb or μg/l. Studies represent a variety of land-uses and other conditions.

METAL	Bellevue, WA[a]	Durham, N.C.[b]	Lodi, N.J.[c]	Castro Valley, CA[d]	Occoquan, VA[e]	Orlando, Fl.[f]
Arsenic	13 (±12)	--	--		--	94
Cadmium	0.7 (±.5)	--	--	10	--	25
Chromium	7 (± 5)	230 (±100)	30	60	83	46
Copper	20 (±12)	150 (±90)	150	60	56	513
Lead	210 (±160)	460 (±380)	900	300	271	1580
Nickel	12 (±4)	150 (± 50)	80	60	18	30
Zinc	120 (±80)	360 (±370)	620	110	211	423

[a] Metro Toxicant Inventory data: 100% residential; 11 storms, 21 samples.

[b] Colston & Tafuri (1975) and Colston (1974): 60% res., 20% comm./indus.; 36 storms, over 500 samples.

[c] Wilber & Hunter (1975).

[d] Metcalf & Eddy (1979).

[e] Randall et al. (1978).

[f] Harper et al. (1979).

Table 15. CONCENTRATIONS OF THREE URBAN RUNOFF METALS FROM THE SEATTLE AREA.

Comparison is made between present study values from Bellevue residential basins and the three land-use types of the Farris et al. (1979) study. Concentrations are in ppb or ug/l.

	Toxicant Inventory	Farris et al. (1979)		
Metal	Residential (Bellevue)	Residential (View Ridge)	Commercial (South Center)	Light Industrial (South Seattle)
	n = 21 mean (sd)	n = 26 mean (sd)	n = 35 mean (sd)	n = 26 mean (sd)
Cadmium	0.7 (±.5)	< 4	< 4	< 5
Lead	210 (±160)	250 (±210)	380 (±310)	220 (140)
Zinc	120 (± 80)	110 (± 83)	190 (±160)	220 (130)

Table 16. METALS IN I-90 FREEWAY RUNOFF

These data represent four storm events from a sampling site on I-90 at the L.V. Murrow (Mercer Island) floating bridge in Seattle. Values are concentrations in μg/l or ppb. (Farris et al., 1973)

	Insoluble		Soluble[a]		Total[b]	
	mean	(min-max)	mean	(min-max)	mean	(min-max)
Cadmium	--	--	--	--	<10	(<4-160)
Chromium	--	--	--	--	<10	(<20-80)
Copper	30	(<10-160)	70	(<10-490)	100	(<10-650)
Lead	1,630	(470-4,520)	150	(<100-440)	1,780	(470-4,980)
Zinc	320	(10-1,260)	80	(< 5-270)	400	(10-1,530)

[a] Soluble values represent levels in filtrate that passed through a 1.2 micron filter; these metals could still be associated with particles of a smaller size.

[b] Total values are the sum of insoluble and soluble for copper, lead, and zinc, and the direct analytical values for cadmium and chromium, which were not filtered.

Table 17. METALS IN I-5 FREEWAY RUNOFF

Data are from two sampling sites on I-5 in Seattle. Values are concentrations in μg/l or ppb. (Chui et al., 1981).

Metal	Site #1 (n = 43)			Site #2 (n = 19)		
	mean	(sd)	range	mean	(sd)	range
Copper	43	(±41)	13-283	43	(±21)	21-112
Lead	466	(±269)	80-1166	760	(±766)	304-3775
Zinc	638	(±672)	112-3093	968	(±1084)	201-4769

Table 18. LOADINGS OF METALS FROM SEATTLE BY LAND-USE TYPE.

Average loading rates per storm event are given in lbs/acre.
(Conversion: lb/acre = 1.12 kg/ha.).

	Toxicant Inventory	Farris et al. (1979)		
Metal	residential	residential	commercial	industrial
Cadmium	0.00002	--	0.0002	0.0002
Lead	0.0035	0.02	0.0146	0.0089
Zinc	0.0020	0.001	0.0068	0.0084

Table 19. LOADINGS OF METALS FROM NATIONAL STUDY.

Average loading rates per storm event (all land-use types pooled)
are lbs/curb mile.[a]
(Sartor and Boyd, 1972.)

	loading (lbs/curb mi)	
Metal	8-city average	Seattle
Cadmium	0.003	0.003
Chromium	0.11	0.081
Copper	0.20	0.075
Lead	0.57	0.50
Nickel	0.05	0.028
Zinc	0.65	0.37

[a] Amy et al. (1974) give an equivalent of 0.46 curb miles per acre of street surface averaged for all land-use types.

NURP data[a] are from USEPA (1982c) and are currently incomplete (Healy, pers. comm.).
[a]The NURP data include 10 of the 21 Metro samples.

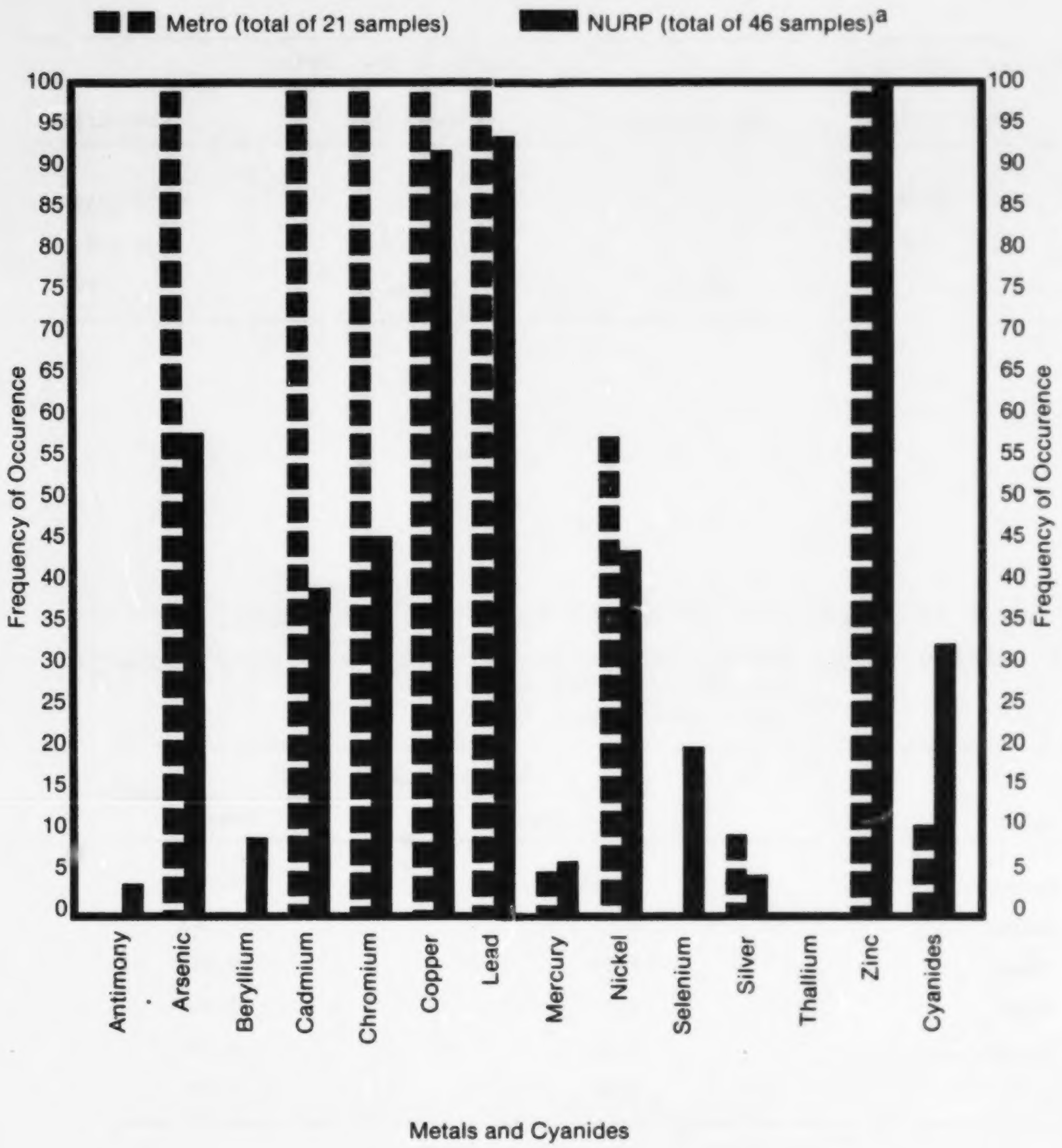
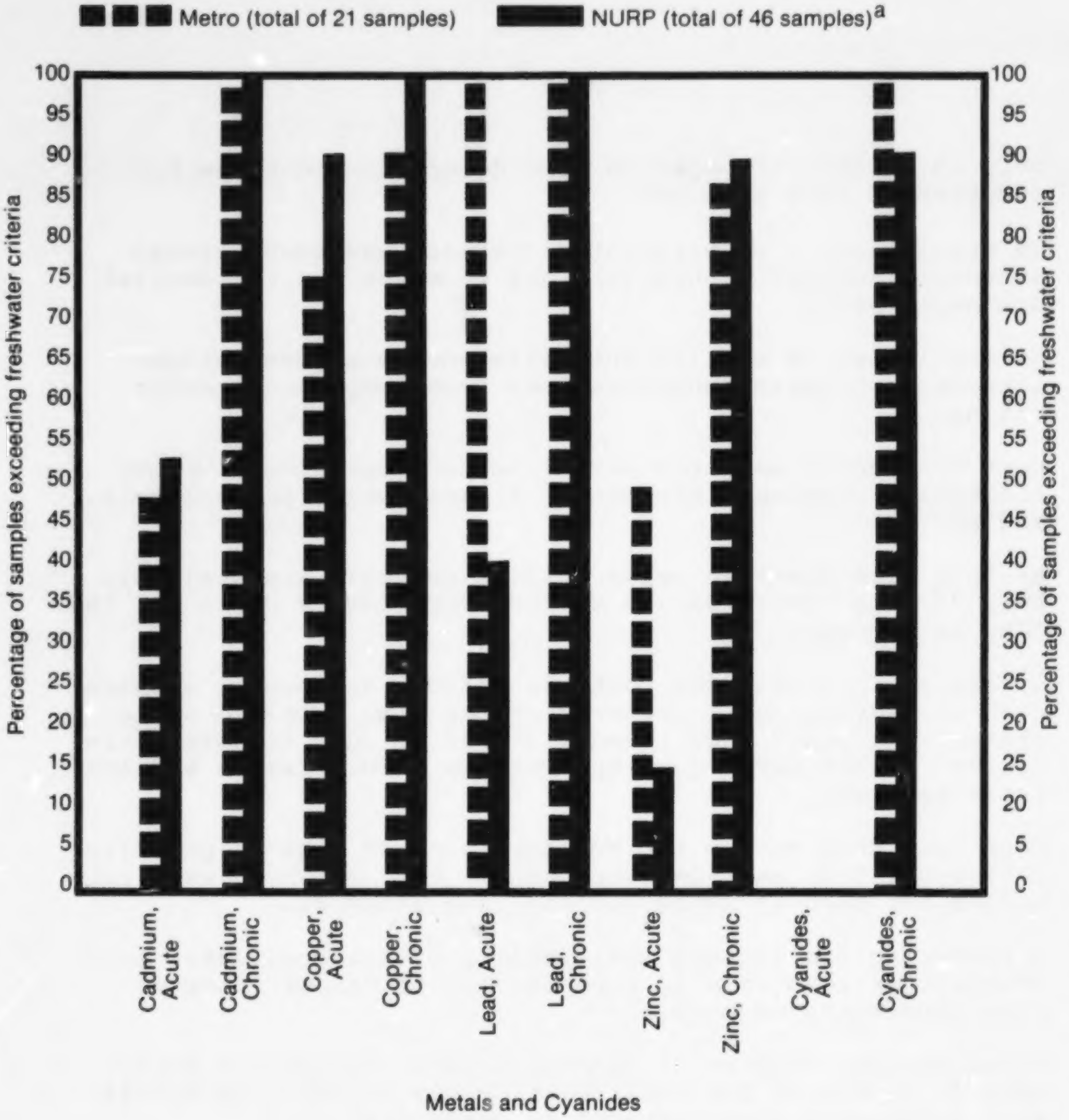


Figure 9.

COMPARISON BETWEEN METRO AND NURP INORGANIC TOXICANT OCCURRENCES IN RUNOFF



NURP data[a] are from USEPA (1982c) and are currently incomplete (Healy, pers. comm.).

[a]The NURP data include 10 of the 21 Metro samples.

Figure 10.

PERCENTAGE OF METRO AND NURP SAMPLES EXCEEDING FRESHWATER QUALITY CRITERIA

2. The Organic Compounds

(Tables for this subsection begin on page 3-25.)

SUMMARY

- Only 19 of the 111 organics were detected, and these had occurrences less than 20%.
- No statistically significant difference was seen between stormwater organic concentrations from the two residential drainage basins.
- No statistically significant difference was seen between stormwater organic concentrations from swept and unswept basins.
- Most frequently detected were lindane (tentative), α-BHC (tentative), pentachlorophenol, fluoranthene, phenanthrene, and pyrene.
- At this time specific water quality criteria are available only for the pesticides; a single criterion is given for the PCBs as a group.
- Of the seven pesticides found in Metro's stormwater samples, each exceeded chronic criteria; three also exceeded acute criteria at least once (reader should be sure to note limitations of the water quality criteria in Discussion and Analysis section).
- NURP data from across the country found 49 organic priority pollutants (35% maximum occurrence), many of which were volatiles not seen in local samples (see Table 22).
- Considering the limited availability of national data, concentrations seen locally were similar to values reported from across the country.
- Fractionation studies of general organic categories found that 71 to 96% of the total extractable organics in runoff were associated with particulate materials.
- Most reported organic analyses measured such general concentrations as oil and grease or total aliphatic and aromatic hydrocarbons which, though they include many more compounds than the priority pollutants, can indicate relative levels of the compounds of concern.

Stormwater runoff data for priority pollutant organics were derived from 21 flow-proportional composite samples -- ten from Surrey Downs and 11 from Lake Hills -- taken between August, 1980, and January, 1982, and analyzed by GC/MS and GC/ECD. Organic compounds were detected in only ten of these samples. Sampling equipment blanks using deionized distilled water were included to check for possible sampler contamination (see Appendix A).

(a) Occurrence. Of the 111 organic priority pollutants, only 19 were detected at least once in Metro's stormwater samples, and, except for one value, all were at or near detection limits (Table 20). What's more, all had very low percentages of occurrence (less than 20%).

(b) Comparison With Criteria. Due to a current lack of adequate toxicity data for the organic priority pollutants, chronic or acute water quality criteria have been established only for the pesticides and PCBs (Table 21). Of the seven pesticides tentatively identified in Metro's stormwater samples, each exceeded chronic freshwater and saltwater criteria (assuming a 24-hour average value) in at least one of its occurrences. Endosulfan, lindane and DDT also exceeded acute saltwater criteria. Again, it should be noted that these criteria are for ambient receiving waters and not undiluted stormwater, but they are useful as points of reference.

(c) Comparison With Other NURP Data. The preliminary NURP results for the 19 participating projects (U.S. EPA, 1982c) found 49 organic priority pollutants in urban runoff. Table 22 presents the 15 compounds that occurred more than ten percent of the time. Among these compounds, only lindane (α-BHC) has established criteria for comparison.

A very limited number (seven) of NURP runoff samples have been searched for non-priority pollutant organic compounds. Results are shown in Table 23.

(d) Comparison With the Literature. The relatively recent advent of GC/MS technology, the difficulty of analysis for very low (part per billion to part per trillion) concentrations of the organic priority pollutants, and the high consts of analysis have resulted in very little being written about the presence of organic compounds in stormwater and in the aquatic environment. Determination of toxic effects, especially chronic exposure problems, remains controversial and quite complex. One expression of this immense data gap is the problem EPA had in attempting to establish water quality criteria: of the 111 organic priority pollutants, criteria could be set for only nine specific compounds, all pesticides (see Table 21).

The only non-NURP priority pollutant analysis of stormwater runoff that we could find was the preliminary, unpublished data from Field and Turkeltaub's group at EPA's Office of Research and Development (Ammon, 1980, in Rolan et al., N.D.). These data are presented in Table 24. Much similarity of identified compounds exists between these data and the Metro and NURP results. The concentration maxima of the PAHs, however, are noticeably higher in the Ammon data. All of these high values were from one sampling site; the remaining sample concentrations were remarkably consistent with Metro and NURP data (Turkeltaub, personal communication).

The only published reference we could find to specific GC/MS analyses of stormwater was a local study of highway runoff by Zawlocki (1981; summary: Zawlocki et al., 1980). She analyzed three Seattle-area samples from I-5 and SR-520 for a wide range of trace organics (not just priority pollutants), splitting her samples into particulate and soluble fractions by filtration through 0.3 micron glass fiber filters. The tentative structural assignment identifications, grouped by class, are listed in Table 25. A very large number of organic compounds were tentatively identified at trace concentrations; almost no overlap exists with Metro, NURP, or the Ammon (1980) data, and a review of the computer data reveals little likelihood of confirmation of many of these identities (Farlow, personal communication).

A quantitative summary of the nine classes is presented in Figure 11. Aliphatics and aromatics represented the major groups by weight in the Zawlocki study. Generally, aliphatic hydrocarbons were more abundant than aromatic compounds in both soluble and particulate fractions. On the average, 75% of the aliphatics and 84% of the aromatics (by weight) were associated with the particulate fraction; 71% of the total chromatographed organics were in the particulate fraction and, in a total of eight storms analyzed for general constituents, 79% of the total extractable organics (TEO) were in the particulate fraction (Table 26). The mean TEO concentration in eight storms was 20 (± 7) ppm (range: 12-31); the mean oil and grease value was 44 (± 25) ppm (range: 15-93). No strong correlations were found between the organic constituents of the samples and any of the conventional parameters such as TSS, VSS, COD or oil and grease. Zawlocki concluded that the major source of organic compounds in highway runoff was petroleum: lubrication oils, fuels, and combustion emissions.

Wakeham (1976; summary: Wakeham, 1977), in a study of aliphatic hydrocarbons in Lake Washington, analyzed some runoff samples from the Seattle area by GC/FID. While he did not identify specific constituents or focus on priority pollutant organics, his measurements of total aliphatic hydrocarbons (the hydrocarbons in a pentane-eluted fraction) are of interest as a more specific indicator of petroleum-originating loads than general oil and grease measurements (see below). He found a mean total aliphatic hydrocarbon concentration of 1.2 (± 1.4) ppm in residential/commercial runoff (storm drains discharging to Lake Washington), and a mean concentration of 12 (± 6) ppm in runoff from the two freeway floating bridges.

The chromatographic character of both measurements indicated used automobile lubricating oil, not gasoline components or combustion, as the likely source of the aliphatics. The much higher loadings from freeway runoff were correlated with traffic volumes. Fluorescence analysis of the runoff samples for aromatic compounds showed napthalenic hydrocarbons and three- and four-ring PAHs. No specific identifications, quantifications, or source designations were made.

Hunter et al. (1979) analyzed runoff from a residential area in Philadelphia for total hydrocarbons by GC/FID. Their results, presented in Table 27, showed an average total hydrocarbon concentration of 3.69 ppm, of which 70% was aliphatic and 30% aromatic, and of which 86% (by weight) was associated with particulate (>1 um) and 14% with soluble (<1 um) constituents. Loadings of total hydrocarbons were calculated at 26 kg/ha/year (23 lb/acre/year). Component characterization in this and a related analysis (MacKenzie and Hunter, 1979) indicated lubricating (crankcase) oil as the primary hydrocarbon source, both aliphatic and aromatic.

Eganhouse and Kaplan (1981), in a study of extractable organic matter in urban runoff, analyzed stormwater in the Los Angeles River (large, multiple landuse, stormdrainage system) using thin-layer chromatography. As shown in Table 28 they found total extractable organic concentrations of 19 ppm (range: 3-33), of which total hydrocarbons (aliphatic and aromatic petroleum residues) averaged 11 ppm or 55% of the total organics; the remainder were fatty acids, polar compounds, ketones and others, many of biological origin. The vast majority (85%) of the total organics were associated with particles; 96% of the total hydrocarbons were so bound. A further characterization of the samples by GC/FID and GC/MS (Eganhouse et al., 1981) showed that the total hydrocarbon fraction was predominantly vehicular exhaust particles and lubricating oils. The following PAHs were identified: napthalene, phenanthrene/anthracene, fluoranthene, pyrene, chrysene, xanthene, and benzopyrene. This latter analysis was felt to be "undoubtedly incomplete," and concentrations for individual compounds were not given.

Acheson et al. (1976), in the course of analytical protocol development for PAHs, analyzed stormwater runoff samples from a British highway by thin-layer and gas-liquid chromatography. Their results (Table 29) led them to the conclusion that "the motorway runoff sample contains high concentrations of PAH."

Oil and grease is a fairly common runoff parameter which represents hexane extraction of hydrocarbons, fatty acids, esters, and other lipids (Wakeham, 1977). Farris _et al_. (1974) found oil and grease concentrations ranging from one to 16 ppm (with a mean of ten ppm) in the residential and commercial runoff samples collected in Seattle. Samples from freeway runoff in Seattle (Dalseg and Farris, 1970; Farris _et al_., 1973; Mar _et al_., 1981) had higher oil and grease concentrations: means of 44, 27 and 40 ppm, respectively. It should be noted that Zawlocki (1981) found little correlation between changes in oil and grease and the extractable organics fraction.

Very few pesticide and PCB analyses on stormwater runoff have been reported in the literature. Table 30 presents a summary of data from Sartor and Boyd (1972), Ellis and Alley (1979), Clark _et al_. (1975), and U.S.G.S. (1972). These results from GC/ECD analyses are tentative (not confirmed) identities and should be used with caution (Farlow, personal communication).

Table 20. ORGANIC COMPOUNDS IN STORMWATER RUNOFF
(Metro Toxicant Inventory Data)

All values are concentrations in ppb or μg/l. Only the ten samples in which organics were detected are presented here; the other eleven samples (as seen in Tables 7 and 8) had no organics above the detection limits.

	Detection Occurrence	#5-Surrey Downs-8/17/80	#15-Surrey Downs-11/3/80	#21-Surrey Downs-2/24/81	#6-Lake Hills-8/17/80	#7-Lake Hills-9/1/81	#14-Lake Hills(swept)-10/31/80	#18-Lake Hills(swept)-1/21/81	#19-Lake Hills(swept)-2/11/81	#42-Lake Hills-10/28/81	#43-Surrey Downs-10/28/81
PESTICIDES:											
Endosulfan	1/21								0.2		
Dieldrin	3/21				0.008				0.1	0.02	
α-BHC	4/21	0.017			0.003					0.06	0.05
γ-BHC(Lindane)	5/21	0.006			0.002				0.9	0.03	0.04
δ-BHC	2/21	0.006			0.007						
DDT	1/21								0.35		
Heptachlor	1/21										0.01
ALIPHATICS:											
Trichloromethane	1/21					0.2					
AROMATICS:											
Benzene	2/21		10				13				
PHENOLICS:											
Phenol	1/21					3[a]					
Pentachlorophenol	4/21	3			115[b]		8		11		

Table 20. (Continued) ORGANIC COMPOUNDS IN STORMWATER RUNOFF.
(Metro Toxicant Inventory Data)

	Detection Occurrence	#5-Surrey Downs-8/17/80	#15-Surrey Downs-11/3/80	#21-Surrey Downs-2/24/80	#6-Lake Hills-8/17/80	#7-Lake Hills-9/1/81	#14-Lake Hills(swept)-10/31/80	#18-Lake Hills(swept)-1/21/81	#19-Lake Hills(swept)-2/11/81	#42-Lake Hills-10/28/81	#43-Surrey Downs-10/28/81
PHTHALATES:											
Di-n-octylphthalate	1/21							0.4			
PAHs:											
Fluoranthene	4/21		2	12				0.3			
Benzo(a)pyrene	2/21		2	1							
3-4-benzofluoranthene	1/21			2							
Chrysene	3/21		3	2							
Phenanthrene	4/21		1	7				0.3			
Pyrene	4/21		6	10				0.3			
Benzo(a)anthracene	2/21		3	1							
Benzo(k)fluoranthene	1/21		4								
Anthracene	1/21			1							

[a] Early sample field blanks contained phenol contaminants in the range 2-8 ppb (see Appendix A); this reported value is disregarded.

[b] Because of unusually high PCP value, analytical lab rechecked sample #16 spectrograms and value was confirmed.

[c] Field blank for sample #15 had 1 ppb fluoranthene as contamination (see Appendix A).

Table 21. AMBIENT WATER QUALITY CRITERIA FOR THE ORGANIC PRIORITY POLLUTANTS [a] (U.S. EPA 1980a)
Concentrations are in μg/l or ppb.

Compound	Freshwater		Saltwater	
	Acute	Chronic	Acute	Chronic
Pesticides:				
Aldrin	3.0	--	1.3	--
Lindane (γ-BHC)	2.0	0.080	0.16	--
Chlordane	2.4	0.0043	0.09	0.0040
DDT	1.1	0.0010	0.13	0.0010
Dieldrin	2.5	0.0019	0.71	0.0019
Endosulfan	0.22	0.056	0.034	0.0087
Endrin	0.18	0.0023	0.037	0.0023
Heptachlor	0.52	0.0038	0.053	0.0036
Toxaphene	1.6	0.013	0.070	--
PCBs (General):	--	0.014	--	0.030

[a] Of all 111 organic compounds, sufficient data to develop criteria existed for only 9 pesticides plus a general level for the 7 PCBs.

Table 22. MOST FREQUENTLY DETECTED ORGANIC COMPOUNDS IN NURP URBAN RUNOFF SAMPLES

Data are from USEPA (1982c) and are incomplete at this time (Healy, pers. comm.). Concentrations are μg/l or ppb.

Organic Compound[a]	%Occurrence[b] (in 68 Samples)	Concentration Range[b] (μg/l)
1,1,1-Trichloroethane	35%	1-23
Benzene	34%	1-13
α-BHC	25%	0.0027-0.9
Trichioromethane (chloroform)	24%	0.2-8
Toluene	24%	3-9
Bis (2-ethylhexyl) phthalate	24%	1-41.5
Pentachlorophenol	18%	1-115
1,2,-trans-Dichloroethene	12%	1-3
Ethylbenzene	12%	1-3
Trichloroethene	12%	1-3
γ-BHC (Lindane)	11%	0.002-0.9
Di-n-butylphthalate	11%	2.8-11
Tetrachloroethene	10%	1-43
4-Nitrophenol	10%	1-19
Phenanthrene	10%	0.3-7

[a] Dichloromethane (methylene chloride) is not included because of high laboratory contamination problems.

[b] The NURP data include 17 of the 21 Metro samples.

Table 23 . TENTATIVE IDENTIFICATIONS OF NON-PRIORITY POLLUTANT ORGANICS REPORTED IN NURP URBAN RUNOFF SAMPLES (U.S. EPA 1982c)

Organic Compound	Estimated Concentration Range (μg/l)	Observations/ Total No. Searches
6-Methoxy-N,N'-bis(1-methylethyl)-1,3,5-triazine-2,4-dione	60-64	1/7
4-Propoxyphenol	8	1/7
Methylheptanal	12	1/7
3-Methyl-2-cyclohexen-1-one	6-9	4/7
1-(2-Butoxyethoxy)ethanol	5-23	2/7
2,2,4-Trimethyl-1,3-pentanediol	17	1/7
Tributylphosphate	6	1/7
9,10-Anthracenedione or 9,10-Phenanthrenedione	20-29	2/7
2,4-Dichlorophenoxyacetic acid or 2,4-D	180	1/7
(1,1'-biphenyl)-carboxaldehyde	17	1/7
Unidentified substituted alkyl hydrocarbon	6-37	3/7
Unidentified substituted alkyl hydrocarbon	10-100	2/7
Unidentified substituted alkyl hydrocarbon oil	10-100	2/7
Unidentified substituted polycyclic aromatic	22	1/7

Table 24. ORGANIC PRIORITY POLLUTANTS IN STORMWATER RUNOFF FROM EIGHT U.S. LOCATIONS
Preliminary data from Ammon (1980).

Priority pollutant	Concentration in runoff, range (ug/l)	Sites reporting[a]
Monocyclic Aromatic Hydrocarbons		
Benzene	0.28-0.46	9,10
Ethylbenzene	0.09	6
Toluene	1.10-7.70	5,6,9
Polycyclic Aromatic Hydrocarbons		
Benzo(a)anthracene (1,2-Benzanthacene)	3.40-50.00	3,11
Benzo(b)fluoranthene (3,4-Benzofluoranthene)	8.60-5.50	3,11
Benzo(k)fluoranthene (11,12-Benzofluoranthene)	8.60-51.50	3,11
Benzo(a)pyrene	170.0	3
Indeno (1,2,3-cd)pyrene	4.30-86.00	3,10
Benzo(ghi)perylene (1,12-Benzoperylene)	1.90-41.00	3,10
Acenaphthene	0.50-1.10	3,11
Acenaphthylene	0.20-0.22	3,11
Anthracene	0.60-26.50	3,11
Chrysene	3.40-50.00	3,11
Fluoranthene	0.03-98.00	1,2,3,6,8,11
Fluorene	0.60-1.00	3,11
Napthalene	1.80	11
Phenanthrene	0.40-26.50	1,3,11
Pyrene	0.08-76.00	1,2,3,6,11
Dibenzo(a,h)anthracene (1,2:5,6-Dibenzanthracene)	7.20	10
Halogenated Aliphatic Hydrocarbons		
Dichloromethane(Methylene chloride)	0.95-4.60	1,4,10
Trichloromethane (Chloroform)	1.10	5
1,2-Dichloropropane	0.10	6
Bromodichloromethane (Dichlorobromomethane)	0.10	5
Trichlorofluoromethane	0.20-2.90	5,10,11
1,1,1-Trichloroethane	2.10	9
Phthalates		
Diethyl phthalate	0.06-0.80	4,5,6,7,10,11
Di-n-butyl phthalate	0.30-3.40	1,2,3,4,5,6, 7,8,11
Bis(2-ethylhexyl)phthalate	2.30-160.0	1,2,3,4,5,6,7,8, 10,11
N-Butyl Benzyl phthalate (Butylbenzyl phthalate)	0.50-5.0	5,11

Table 24. ORGANIC PRIORITY POLLUTANTS IN STORMWATER RUNOFF FROM EIGHT U.S. LOCATIONS (Continued)

Priority pollutant	Concentration in runoff, range (ug/l)	Sites reporting[a]
Monocyclic Aromatic Hydrocarbons (Phenols)		
Phenol	0.30-0.85	2,3,4,5,7,8,11
Pentachlorophenol	0.90-0.90	5,7,8
2,4-Dimethyl phenol	0.50-0.70	7,8
2,4,6-Trichlorophenol	0.30	7
Nitrosamines and Other N Compounds		
Diphenyl Nitrosamine (N-Nitro sodiphenylamine)	0.80	11

[a] Key to sites:

1: Lawrence Shopping Center, near Trenton, NJ.

2: Same as #1.

3: Lake Eola, Orlando, FL.

4: Same as #3.

5: Storm sewer, Austin, TX.

6: Storm drain outfall, St. Helens, OR.

7: Storm drain outall, Coyote Creek, San Jose, CA.

8: Same as #7.

9: Storm sewer, Rochester, NY.

10: Storm sewer, New Roxbury, MA.

11: Highway runoff, Interstate 94, Milwaukee, WI.

Table 25. ORGANIC COMPOUNDS TENTATIVELY IDENTIFIED IN HIGHWAY RUNOFF FROM SEATTLE

X=detected, not quantified; number=approximate concentration in ppb. (Zawlocki, 1981)

NBS LIBRARY IDENTIFICATIONS	STORM 1-5-87		STORM 1-5-131		STORM 520-43	
	Soluble	Particulate	Soluble	Particulate	Soluble	Particulate
	ALIPHATIC HYDROCARBONS					
Undecane	X	X	X	X		2
Dodecane	X					
1-Hexadecene	2					
Hexane, 2,5-Dimethyl	X					
Decane				X		X
Octane,2,7-Dimethyl	X					X
Decane,2,5-Dimethyl	X					
Pentacosane	2	7				
Heptane,3,-Dimethyl	X		X			
Octadecane	4					
Heptane,2,6-Dimethyl-						X
Eicosane	X					
Hexatriacontane	5	3				2
Heptane,5-Ethyl-2-Methyl	X		3	X	X	
Hexane,3,-Dimethyl				X		X
Octacosane						X
Decane,5-Ethyl-5-Methyl						X
1,4-Hexadiene,2,4,5,5-teramethyl						X
1,4-Undecadiene						X
*Nonane,2-Bromo-5-Ethyl				2		X
Pentane,2,2,3,3-Tetramethyl					X	
Butane,2,2-Dimethyl		X				
Tridecane,2-methyl		X				
Hexane,3-methyl					X	
1-nonene,4,6,8,-trimethyl			X	7		
Hexane,3,3,4-trimethyl				X		
methyl				X		
Pentalene,Octahydro-1-(2-Octyldecyl)				X		7
*Dodecane,2,2-dibromo				X		
*Octane,2-Bromo		X	2	X	X	
*Decane,3-Bromo		2	3		X	X
Cyclohexane,1-ethyl-11-methyl-cis-				2		
Heptane,2,3-dimethyl				X		
Heptane,3-methyl				X		
Butane,2,2,3-trimethyl				X		
Undecane,2-methyl				X		
Hexane,2,4,4,-trimethyl			X	2		
*Propane-2,3,dichloro-2-methyl				X		
Dodecane,2-methyl			2			
Pentane,3-ethyl			X			
Decane,5,6-dis(2,2,-dimethyl-propylidene)-(E,Z)			X			
Nonane,5-butyl			X			
Nonane,2-methyl			X			
	KETONES AND ALDEHYDES					
Ethanone,1-(methylphenyl)-		X				
2,5-Cyclohexadiene-1,4-Dione		X				
4,5-Octadiene-3-One,2,2,7,7-tetramethyl		X				X
1,2-Benzisothiazol-3(2H)-one		X				
3-Penten-2-One,3,4,-Dimethyl-						X
4H-Pyrazole[3,4,-D]Pyrimidin-4-one, 1,5-dihydro					X	X
1,3-Isobenzofurandione				X		X
4-Heptanone,2,2,3,5,5,6,6-Octamethyl						X
9,10-Anthracenedione,2-methyl				X		X
2-propanone,1,1,3,3-tetrachloro				X		
4,7,(1H,8H)-pteridineione,2-amino				X		
1-propanone,1-(1,4-dimethyl-3-cyclohexen-1-yl)-2-methyl				X		
2(3H)-furanone,5-ethenyl-dinydro-5-methyl				X		
3-nonen-2-one				X		
3-Hepten-2-one				X		
Ethanone,2-chloro-1-phenyl				X		

*Mistaken identities placed into correct category; determined by manual examination of mass spectra.

Table 25. ORGANIC COMPOUNDS TENTATIVELY IDENTIFIED IN HIGHWAY RUNOFF FROM SEATTLE (Continued)

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NBS LIBRARY IDENTIFICATIONS	STORM 1-5-87		STORM 1-5-131		STORM 520-43	
	Soluble	Particulate	Soluble	Particulate	Soluble	Particulate
Ketones and Aldehydes Con't.						
1H-Imidazdle-2-carboxaldehyde, 1-phenylmethyl)-				X		
1H-Indene-1-one,2,3,-dihydro-			X			
1(3H)-Isobenzofuranone			X			
Ethanone,1-cycloheyxl			X			
1,4-Benzenedicarboxaldehyde,2-methyl			X			
2-Cyclohexen-1-one,2,2,4-Trimethyl-3-(1-oxobutyl)-			X			
3-Hexanone,2-4-dimethyl			X			
2-Pentenal,2-methyl			X			
OXYGENATES						
Propane,2-methoxy-2-methyl	X		X			
Phosphoric acidtributyl ester	X					
1,2-Benzenediol,4-(2,2-dihydroxy ethyl)-	X		X			
Decanoic acid,8-methyl,methylester	X					
Undecanoic acid,methyl ester	X					
1,2-Benzenedicarboxylic acid, butyl 2-methylpropyl ester	X		X			
1,2-Benzenedicarboxylic acid, dimethylester		X				
1,3-Dioxolane,2-pentadecyl		X				
Diazene,methyl phenyl-1,Oxide,(e)-		X				
Benzene acetic acid, o-methoxy-methyl-ester		X				
Thiocyanic acid, phenyl ester		X				
9-Hexadecenoic acid,methylester,(Z)-		X				
Heneicosanic acid,methylester		2				
Hexanoic acid,4-methyl-,methylester				X		
Octadecane,1-(ethenyloxy)			X			
*Tetradecane,1-chloro		X				
4-8-dioxatricyclo[5.1.0.03,5]octane, 1-methyl-5-(1-methylethyl)-						X
Nonanoicacid,7-methyl,-methylester				X		X
1,3-Isobenzofurandione				X		X
Propanoic acid,2-methyl,-butylester			X			X
4-octenoic acid,6-ethyl-3-hydroxy-2,7-dimethyl,methyl ester			2	3		2
6-octen-1-ol,3,7-dimethyl-propanoate				X		
2(3H)-furanone,5-ethenyldihydro-5-methyl)				X		
Oxirane,(3,3-dimethylbutyl)				X		X
1,2-benzenedicardoxylicacid, diisooctyl ester			X	X		X
4-hexenoic acid,3-methyl-1,6,dioxo-			2	38		27
3-buten-2-ol,4-(2,2,6-trimethyl-7-oxabicycid [4.1.0]Hept-1-yl)-						2
2H-Pyran-2-carboxylicacid,3,6,-dihydro-4,5-dimethyl-,methyl ester				2		5
Acetic acid,(m-hydroxy phenyl)-,ethylester						X
Tetradecanoic acid						X
Hexadecanoic acid				X		X
Octadecanoic acid						X
1,2,3-propenetriol,triacetate			X		X	
Ethanol,1-(2-butoxyethoxy)-					X	
2-Buten-1-one,1-(2,6,6-trimethyl-7-oxabicyclo[2.2.1]Hept-2-En-1-yl)-				X		
Indole-2-propionicacid methylester				X		
Pentanoic acid,4,4-dimethyl-3-methylene-,ethyl ester				X		
*Nonane 2-bromo-5-ethyl				2		
Octane,1,1'-oxybis-				X		
1,2-benzenedicarboxyliacid, diethylester			X	X		
Isoxazole,4-Iodo-3-phenyl				X		
Heptanoic acid				X		
Hexane 1,1'-oxybis(2-ethyl-			X			

*Mistaken identities placed into correct category; determined by manual examination of mass spectra.

Table 25. ORGANIC COMPOUNDS TENTATIVELY IDENTIFIED IN HIGHWAY RUNOFF FROM SEATTLE (Continued)

NBS LIBRARY IDENTIFICATIONS	STORM 1-5-87		STORM 1-5-131		STORM 520-43	
	Soluble	Parti-culate	Soluble	Parti-culate	Soluble	Parti-culate
	Oxygenates Con't.					
Acetic acid (trimethsiloxy)-trimethyl silyl ester			X			
Ethanol,2-(1-methyl ethoxyl-			X			
1(3H)-Isobenzothanone			X			
Ethanol,2-[2-(2-butoxyethoxy)Ethoxy]-			3			
2-Cyclohexen-1-one,2,2,4-trimethyl-3-(1-oxobutyl)-			X			
2,5,8,11-Tetraoxadodecane			2			
1-propanol,2-(2-methoxy-1-methylethoxy)-			X			
2-propenoic acid,2-[(trimethylsilyl)oxy]-trimethylsilyl ester			X			
Nonanoic acid			X			
	AROMATIC COMPOUNDS					
Benzothiazole	X	X	X			
1,2-benenediol,4-(1,2-dihydroxy ethyl)-	X		X			
Thiocyanic acid,phenyl ester	X					
1,2-benzene dicarboxylic acid, butyl,2-methyl propylgster	X		X			
Benzene,1,3-dimethyl		X				
Ethanone,1-(methyl phenyl)-		X				
Benzene,1-ethyl-2,4-dimethyl		X				
Benzene,4-ethyl-1,2-dimethyl		X		X		
1,2-benzedicarboxylic acid, dimethyl ester		X				
Benzothiazole,2-(methylthio)-		X				
Diazene,methyl phenyl-,1-oxide,(e)-		X				
Benzene acetic acid, α-methoxy-, methyl ester		X				
Thiolyanic acid, phenul ester		X				
Acetamide, N-(3-methyl phenyl)-		2				
Benzene,1,2,3,-Trimethyl				2		X
1,2,3-Benzothiadiazole		X				
Benzene,(1-methylathylidene) cyclopropyl-		X				
Acetic acid,(m-hydroxyphenyl),-ethylester						X
Benzene,1-methyl-4-(1-methylethyl)-						X
1,2-Benzisothiazole						X
1,3-Isobenzoeurandione				X		X
1,2-Benzenedicarboxylic acid, diisooctylester			X	X		X
4H-pyrazolo[3,4-D]pyrimioin-4-one, 1,5-dihydro					X	X
2H-Pyran-2-Carboxylic acid,3,6-dihydro-4,5-dimethyl-methylester				2		
Indole-2-propionic acid methylester				X		
1-8-naphthridine,4-5-dimethyl			X	X		X
9,10-athracenedione,2-methyl				X		X
phenanthrene,3-methyl						X
2(3H)-furanone,5-ethenyldihydro -5-methyl				X		
Benzene,(1-methylethyl)-				X		
Benzene,(2,4,-trimethyl)				X		
Benzene,1,2-diethyl				X		
Ethanone,2-chloro-1-phenyl				X		
1,2-Benzenedicarboxylic acid, diethylester			X	X		
1H-Imidazole-2-carboxaldehyde,1-(phenylmethyl)				X		
Naphthalene,decahydro-,trans				X		
Phenanthrene,2-methyl				X		
Benzo[C]Cinnoline,4-methyl			X			
1(3H)-Isobenzofurandione			X			
1,4-Benenedicarboxaldehyde,2-methyl			X			
	HALOGENATED COMPOUNDS					
2-propanone,1,1,3,3-tetrachloro						X
Dodecane,1,2-dibromo-						2
Nonane,2-bromo-5-ethyl				X		
Propanal,2,3-dichloro-2-methyl			2			

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Table 25. ORGANIC COMPOUNDS TENTATIVELY IDENTIFIED IN HIGHWAY RUNOFF FROM SEATTLE (Continued)

NBS LIBRARY IDENTIFICATIONS	STORM 1-5-87		STORM 1-5-131		STORM 520-43	
	Soluable	Parti-culate	Soluable	Parti-culate	Soluable	Parti-culate
NITROGEN CONTAINING COMPOUNDS						
Benzothiazole	X	X				
Thiocyanic acid, phenyl ester	X	X				
Aceamide,N-(3-methylphenyl)-		X				
Benzothiazole,2-(methylthio)-		X				
1,2-Benzisothiazol-3(2H)-one		X				
1,2,3-Benzothiadiole		X				
1,2-Benzothiazole						X
4H-Pyrazolo[pyrimidin-4-one 1-5-dihydro					X	X
1-8-naphthyridine,4,5-dimethyl			X	X		X
4,7-(1H,16H)-Pteidinedione,2-amino						X
Formamide,N-methyl					X	
Indole-2-propionic acid,methyl ester				X		
1H-imidazole-2-carboxyaldehyde,1-(phenylmethyl)-				X		
Isoxazole,4-Iodo-3-phenyl				X		
Benzo[C]-cinnoline-4-methyl			X			
ORGANOSULFUR COMPOUNDS						
Benzothiazole	X	X	X			
Thiocyanic acid,phenylester	X	X				
Benzothiazole,2-(methylthio)-		X				
1,2-Benzisothiazol-3(2H)-one		X				
1,2,3-Benzothiaiazole		X				
1,2-Benzisothiazole						X
ALCOHOLS						
2,6,10-Dodecatrien-1-Ol,3,7,11-trimethyl-(Z,E)-	X					
1-Pentanol,4-methyl-2-propyl	X		2	4		X
Tridecanol				X		X
3-Buten-2-OL,4-(2,2,6-trimethyl-7-Oxabicyclo[4.1.0]Hept-1-YL)-						2
1-Hexanol,2-Ethyl-2-propyl-				X		X
2,3-Boranediol,endo-2,exo-3-			X	2		4
Cyclohexanol,2-methyl-5-(1-methylethyl-, (1α,2α,5α)						X
1-pentanol,2 ethyl-4-methyl			X			X
1-heptanol,-2-propyl						X
1,2,3-propanetriol,triacetate			X		X	
Ethanol,1-(2-Butoxyethoxy)					X	
2-Buten-1-one,1-(2,6,6-trimethyl-7-oxa-bicyclo[2.2.1]Hept-2-En-1-YL-				X		
Cyclohexanol 4-Ethyl-4-methyl-3-(1-methyl)-,(1-α,3-β)				X		
Nonadecanol				X		
6-Octen-1-Ol,3,7-bimethyl-,propaniate				X		
Ethanol,2-(tetradecyloxy)-				X		
3-Penten-1-OL,2,2,4-Trimethyl			3	X		
1,4-Butanediol,2,3-Bis(methylene)-				X		
1-Heptanol,6-Methyl				X		
1-Dodecanol			X			
Ethanol,2-(1-methylethoxyl)-			X			
Ethanol,2-[2-(2-Butoxyethoxyl)ethoxy]-			3			
1,2-Benzediol,4-(1,2-Dihydroxyethyl)-			X			
1-proanol,2-(2-methoxyl-methylethoxy)-			X			
PHENOLS						
1,2-Benzenediol,4-(1,2-dihydroxyethyl)-	X		X			
Phenol,4-(1,1,3,3-tetramethylbutyl)-	X	X				
Phenol		X				
Phenol,2,6-Bis(1,1-Dimethylethyl)-4-methyl		X				
Phenol,4-(2,2,3,3-tetramethylbutyl)-		X				
Phenol,nonyl		X				
Phenol,2-(1,1-dimethylethyl)-		X				

Table 26. POLLUTANT CONCENTRATIONS AND MASS LOADINGS FROM HIGHWAY RUNOFF (Zawlocki, 1981)

The classes or categories of organic compounds listed are not mutually exclusive. T = trace (not quantified).

PARAMETER	STORM 520-16		STORM 520-43		STORM I-5-131		STORM I-5-87		STORM I-5-79		STORM I-5-79		STORM I-5-93		STORM 520-11	
	mg/l	lb/ acre	mg/l	lb/ acre	mg/l	lb/ acre	mg/l	lb/ acre	mg/l	lb/ acre	mg/l	lb/ acre	mg/l	lb/ acre	mg/l	lb/ acre
Particulate	147	16.3	362	45.8	123	19.2	63	12.	95	4.4	23	1.5	128	28.1	404	89.0
TSS	144	15.9	408	51.6	57	8.9	72	14.	97	4.5	32	2.1	118	25.9	435	95.8
VSS	53	5.9	74	9.4	19	2.97	10	2.0	26	1.2	12	0.79	26	5.7	115	25.3
COD	130	14.4	280	35.4	166	25.9	59	12	61	2.8	61	4.0	52	11.4	271	59.7
Pb	0.5	0.05	0.9	0.1	0.7	0.11	0.3	0.06	0.8	0.04	0.1	0.007	0.8	0.2	0.8	0.2
Particulate Extract	19.1	2.1	17.6	2.2	13.4	2.1	13.5	2.66	15.6	0.72	7.3	0.48	0.5	2.1	30.8	6.79
Aqueous Extract	2.7	0.4	4.6	0.6	9.3	1.4	1.1	0.22	7.8	0.36	5.1	0.33	3.0	0.66	0.62	0.14
Alcohols			0.453	0.057	0.633	0.099	0.16	0.032								
Aliphatic			0.933	0.118	2.49	0.389	6.93	1.37								
Aromatic			0.724	0.092	0.393	0.061	2.20	0.43								
Halogens			0.114	0.014	0.082	0.013	T	T								
Ketones/Aldehydes			0.513	0.065	0.126	0.020	1.13	0.22								
Organo Sulfur			0.005	0.0006	0.005	0.001	1.26	0.25								
Oxygenates			2.57	0.325	3.74	0.586	3.58	0.71								
Phenols			T	T	0.003	0.0005	2.91	0.57								
Nitrogen			0.46	0.058	0.115	0.018	1.148	0.29								

Table 27.

CONCENTRATION OF HYDROCARBONS IN RUNOFF FROM PHILADELPHIA

Values are average concentrations from five storm events, in mg/l or ppm. Separation into particulate and soluble fractions was by centrifugation, with particulates >1 micron. (Hunter et al., 1979.)

Hydrocarbon type	Particulate mean (sd)	Soluble mean (sd)	Total mean (sd)
aliphatic	2.28(±1.08)	0.29(±0.15)	2.57(±0.96)
aromatic	1.01(±0.43)	0.11(±0.07)	1.12(±0.38)
total	3.29(±1.45)	0.40(±0.22)	3.69(±1.26)

Table 28.

CONCENTRATIONS OF EXTRACTABLE ORGANICS IN RUNOFF FROM LOS ANGELES

Values are average concentrations from eleven samples, in mg/l or ppm. Separation into particulate and soluble fractions was by glass fiber filtration, with particulates >1.6 micron. (Eganhouse and Kaplan, 1981.)

Organic Type	Total (unfiltered)		Soluble (filtered)			Particulate (by difference)	
	mean (n=11)	(sd)	mean (n=11)	(sd)	% of total	mean	% of total
total extractable organics	19.2	(10.3)	2.96	(±1.08)	15%	16.2	85%
total hydrocarbons	10.6	(6.8)	0.39	(±0.05)	4%	10.2	96%

Table 29. PAHs IN HIGHWAY RUNOFF

Analyses of British motorway runoff were by thin-layer and gas-liquid chromatography. Values are concentrations in µg/l = ppb. (Acheson et al., 1976)

Compound	Thin-layer Chromatography	Gas-liquid Chromatography
Fluoranthene	1.10	0.49
Pyrene	--	0.43
Benzo(a)anthracene/Chrysene	--	0.39
Benzo(k/j/b) fluoranthene	0.32	0.49
Benzo(a/e) pyrene	0.65	0.57
Perylene	0.20	0.52
Indeno (1,2,3-c,d) pyrene	0.32	0.14
Benzo(g/h/i) perylene	0.12	0.07

Table 30. PESTICIDES AND PCBs REPORTED IN URBAN RUNOFF
All data are concentrations in ppb = µg/l. ND = not detected; - = not analyzed for.

Compound	8 cities average[a]	Denver[b]	Racine, Wisc.[c]	Hayward, Cal.[d]
Aldrin	-	ND	ND	0.004
Chlordane	-	0.6	-	0.56
DDD	0.082	ND	0.022	0.006
DDE	-	<0.02	ND	0.016
DDT	0.075	ND	0.052	0.13
Diazinon	-	0.4	-	0.195
Dieldrin	0.028	<0.01	<0.07	0.09
Endrin	<0.002	ND	<0.2	ND
Heptachlor	-	<0.25	ND	ND
Heptachlor Epoxide	-	<0.04	<0.03	ND
Lindane	<0.01	0.03	<0.11	0.031
Malathion	-	<1.8	-	0.128
Methoxychlor	<1.5	-	ND	-
2,4-D	-	2.6	-	0.57
2,4,5-T	-	<0.04	-	0.063
Total PCBs	0.77	ND	-	-

[a] Sartor and Boyd (1972), many different land use types.
[b] Ellis and Alley (1979), residential area.
[c] Clark et al. (1975), land use unknown.
[d] U.S. Geological Survey (1972), land use unknown.

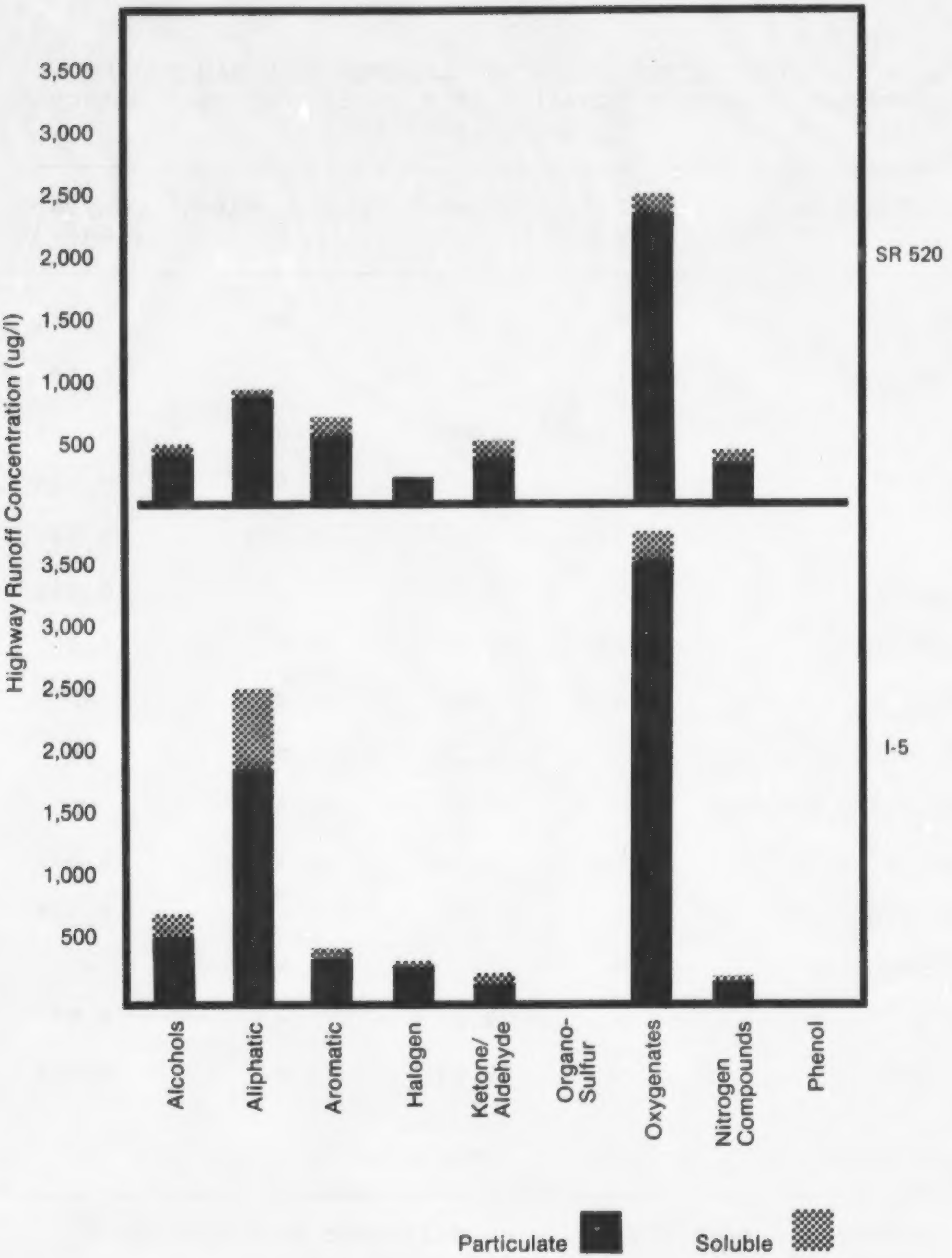


Figure 11.

CONCENTRATIONS IN SOLUBLE AND PARTICULATE FRACTIONS OF NINE ORGANIC CLASSES IN TWO HIGHWAY RUNOFF SAMPLES (Zawlocki, 1981)

B. SOURCES OF TOXICANTS IN RUNOFF

1. Street Dust

As mentioned in the Experimental Design section (II B), the primary contributor of many priority pollutants to stormwater runoff is the dust and dirt on the urban street surface. To measure the concentrations of the inorganic and organic toxicants in this "source," Metro had 14 street dust samples analyzed from areas representative of the major landuse types: Surrey Downs and Lake Hills are single family residential neighborhoods, 148th Avenue SE is a main suburban arterial, Fourth Avenue South at Michigan Street typifies the South Seattle light-industrial area, Third Avenue was chosen as an example of the central business district, and Elliott Avenue serves a busy commercial area.

(a) The Metals. (Tables and figures for this subsection begin on page 3-45.)

SUMMARY

- All of the inorganic priority pollutants except selenium were detected in street dust; the eight having 100% occurrence were (from highest to lowest): lead, zinc, chromium, copper, nickel, arsenic, cadmium, and beryllium (see Table 31).
- Metro's street dust concentration data presented no clear differences between levels in the two residential basins, or between the principle landuse types -- residential, commercial, industrial -- sampled.
- Street sweeping did not appear to reduce metal concentrations in the residential road dust.
- The metals seen in the highest concentrations in street dust tend to be the same as those in stormwater and tend to exhibit the same ranking (see Table 34).
- As in the stormwater literature, potential differences between street dust concentrations from differing landuses are masked by variability in the data.
- While comparisons are complicated and questionable due to differences in analytical sensitivities, metal concentrations in the Metro study area appear to be lower than national averages (except for arsenic).

- The concentrations of metals tend to be highest in the finer-sized particles; but these same fine particles account for only a small portion of the total solids loading on street surfaces.

- Occurrence. Table 31 presents the results of these analyses for the toxic metals and cyanides. Eight of the 14 inorganic toxicants were found in every one of the street dust samples that were analyzed for inorganics; only thallium (detected in three of 12 samples) and selenium (undetected) were in less than half the samples. Ranking the metals and cyanides by order of concentration, the eight with 100% occurrence are: lead, zinc, chromium, copper, nickel, arsenic, cadmium and beryllium.

  Lake Hills had slightly higher concentrations of cadmium, copper and zinc in the dust than Surrey Downs, as shown in Table 32, but the small sample sizes coupled with the nonsignificance of the other differences limit meaningful comparisons between the two basins. Pooling the data for an average residential value simplified analysis.

  No one landuse type had consistently higher or lower concentrations, as shown in Figure 12 and Table 33, for the eight major metals observed. Confidence limits around the means tend to be large, and, with so few data points per landuse type, even differences found to be significant statistically (see Table 33) are questionable because of the small sample size.

  Sample #13, taken during the period when Lake Hills was heavily swept, showed no appreciable differences in metal concentrations; in fact, this swept-basin sample contained the highest lead and beryllium values.

- Comparison With Metro's Stormwater Findings. Table 34 compares the rankings of the six metals seen in the highest concentrations in stormwater and street dust; chromium exhibited the only major variation in the rankings.

- Comparison With the Literature. A number of studies have analyzed urban street dust for heavy metal concentrations and loadings. The best overview of existing data nationwide was presented by Bradford (1977) as a summary of the Amy *et al*. (1974) study which reviewed data from 12 previous studies for general trends. His summary of six metals in various landuse types is shown in Table 35, along with our local data. Only the commercial lead value differed significantly from other land uses among all the metals data analyzed by Bradform using Student's T-test (at p = 0.05). As can be seen from the percent standard error ranges, the national data are quite variable. Local data, also variable, were significantly lower than the national averages for cadmium, chromium and lead, but not for the other metals.

Pitt and Amy (1973), in one of the studies used by Bradford, analyzed street dust from eight U.S. cities, including Seattle. Their results are shown in Table 36 for all eight cities combined and for Seattle alone, along with our local data. Of their nationwide landuse averages, only the industrial chromium and commercial lead and zinc differ significantly from the other values; other statements of differing concentrations found in Pitt and Amy are unsubstantiated by the variability of their data. Some differences exist within the Seattle-only data and between them, the Metro results, and the nationwide averages, but the small sizes for these local data limit credible comparisons.

A study by Wilber and Hunter (1979) compared total toxic metal concentrations in street sweepings less than 63 microns in size from areas of residential and industrial landuse in Lodi, New Jersey. Table 37 lists the five priority pollutant metals studied and their respective values. While residential concentrations are roughly comparable with those of the previous tables, the industrial values are substantially higher (confidence limits not known), reflecting some concentrated sources not generally found in other studies. Analyses of exchangeability, reducibility, and solubility led Wilber and Hunter to conclude that lead, zinc, copper and nickel in street dust and stormwater solids are "available" (present in easily ionizable form) in the following portions: 21%, 17%, 13%, and 4%, respectively.

Data from Shaheen's (1975) analysis of street dust from the commercial/arterial land use of central Washington, D.C. is presented in Table 38. These results, from a large number of samples, reinforce the inherent variability observed in the previous tables.

Results of street dust analyses from a study in Urbana, Illinois (Hopke et al., 1980) are presented in Table 39. These data are from commercial arterial samples and are compared in the table with our commercial and suburban arterial results.

Part of a study conducted by the Puget Sound Air Pollution Control Agency (Baily, 1981) examined the concentrations of toxic pollutants in road dust collected from two Seattle residential communities, North Park and South Park. Table 40 compares the average metal concentrations from these Seattle sites with average values from the Bellevue residential study areas. Cadmium, copper and nickel concentrations were significantly higher in the Seattle samples, while lead and zinc concentrations were similar.

Various studies have explored the association of metals with different size fractions of street surface particles. Pitt and Amy (1973) have done the most thorough analyses. Their results for Seattle street dust, by concentration and by percentage, are shown in Figures 13 and 14, respectively.

These studies, while exhibiting much variability in results as well as in selection of size classes, demonstrate that the concentrations of metals tend to be highest in the finer particle sizes. But these fines account for only a small portion of the total loading of solids on street surfaces (Sartor et al., 1974). In general, half of the metals are associated with particles less than 250 microns in size. The significance of this finding is further discussed in this report's section on potential control measures.

Table 31. METALS IN STREET DUST
(Metro Toxicant Inventory Data)

All values are concentrations in ppm or mg/kg.
Less than (<) values represent detection
limits for undetected parameters.

	Occurrence	Residential					Suburban Arterial			Industrial		Commercial		Mean Concentration	Standard Deviation
		#11 Surrey Downs 10/14/80	#12 Surrey Downs Replic. of #11	#32 Surrey Downs 7/28/81	#13 Lake Hills 10/13/80 (swept)	#34 Lake Hills 7/27/81	#33 148th Ave. SE 6/25/81	#30 148th Ave. SE 8/6/81	#31 148th Ave. SE Replic. of #30	#57 4th Ave. S.&S. Michigan 3/18/82	#60 4th Ave. S.&S. Michigan Replic. of #57	#58 3rd Ave. thru CBD 3/18/82	#59 Elliott Ave. 3/18/82		
Antimony	8/12	<1	<1	0.7	<1	0.4	1.0	<0.2	1.2	1.5	2.0	1.3	1.4	0.8[a]	0.2[a]
Arsenic	12/12	18	39	24	26	12	11	16	22	34	47	17	29	25	11
Beryllium	12/12	0.33	0.34	0.23	0.38	0.22	0.19	0.17	0.19	0.29	0.3	0.26	0.27	0.3	±0.07
Cadmium	12/12	0.6	0.8	0.71	1.1	1.6	0.69	0.66	0.65	0.9	2.0	1.1	1.3	1	± 0.4
Chromium	12/12	20	30	130	40	110	180	120	160	40	59	230	42	97	± 69
Copper	12/12	31	38	42	56	76	260	52	69	84	150	69	190	93	± 70
Lead	12/12	820	520	98	1300	100	90	150	110	380	540	980	1100	520	± 440
Mercury	9/12	0.033	0.042	<0.05	0.076	0.10	<0.05	<0.05	0.10	0.02	0.09	0.18	0.04	0.06[a]	±0.02[a]
Nickel	12/12	20	28	26	27	31	43	35	35	29	44	27	40	32	±7
Selenium	0/12	<2	<2	<3	<2	<3	<3	<3	<3	<0.6	<0.6	<0.6	<0.6	0	-
Silver	6/12	0.01	0.04	<0.5	0.12	<0.5	<0.5	<0.5	<0.5	0.3	0.5	0.1	0.3	0.1[a]	±0.2[a]
Thallium	3/12	0.26	0.29	<1	0.34	<1	<1	<1	<1	<0.2	<0.2	<0.2	<0.2	-	-
Zinc	12/12	180	170	210	230	280	300	330	400	110	970	210	310	310	±220
Cyanides	3/12	<0.1	≤0.1	0.7	0.20	0.7	<0.2	0.3	0.4	<0.05	0.09	0.16	0.06	0.2[a]	±0.1[a]

[a] Estimates of $\overline{x}$ and s are based on Aitchison's delta distribution (see Appendix B).

Table 32. METALS IN STREET DUST FROM THE RESIDENTIAL AREAS. (Metro Toxicant Inventory Data)
Concentrations are in ppm=mg/kg. Student's t-test was used to assess differences.

	Surrey Downs (n=3) mean ± sd	Lake Hills (n=2)	Signif. Diff between means (p=0.05)	Average Residential (n=5)
Arsenic	27 ± 11	19 ± 10	no	24 ± 10
Beryllium	0.3 ± .06	.3 ± .1	no	0.30 ± 0.07
Cadmium	0.7 ± 0.1	1.4 ± .4	yes	1.0 ± 0.4
Chromium	60 ± 60	75 ± 50	no	66 ± 50
Copper	37 ± 6	66 ± 14	yes	49 ± 18
Lead	480 ±360	700 ±850	no	570 ± 510
Nickel	25 ± 4	29 ± 3	no	26 ± 4
Zinc	190 21	260 ± 35	yes	214 ± 44

Table 33. METALS IN STREET DUST FROM DIFFERENT LAND-USE TYPES (Metro Toxicant Inventory Data)

Statistics are from data in Table 31. Concentrations are in ppm or mg/kg. Significant difference between means (+) is based on Student's t-test.

				Significant Diff. between means (p=0.05)			
	n	mean	sd	res.	art.	ind.	com.
1. LEAD:							
residential	5	570	± 510		+	-	-
arterial	3	120	± 30	+		+	+
industrial	2	460	± 110	-	+		+
commercial	2	1040	± 85	-	+	+	
2. ZINC:							
residential	5	214	± 44		+	-	-
arterial	3	343	± 51	+		-	-
industrial	2	540	± 608	-	-		-
commercial	2	260	± 71	-	-	-	
3. CHROMIUM:							
residential	5	66	± 50		+	-	-
arterial	3	153	± 31	+		+	-
industrial	2	50	± 13	-	+		-
commercial	2	140	± 130	-	-	-	
4. COPPER:							
residential	5	49	± 18		-	-	-
arterial	3	127	± 115	-		-	-
industrial	2	117	± 47	-	-		-
commercial	2	129	± 86	-	-	-	

Table 33 (Continued). METALS IN STREET DUST FROM DIFFERENT LAND-USE TYPES
(Metro Toxicant Inventory Data)

			Significant Diff. between means (p=0.05)			
	n	mean (sd)	res.	art.	ind.	com.
5. NICKEL:						
residential	5	26 ±4		+	-	-
arterial	3	38 ±5	+		-	-
industrial	2	36 ±11	-	-		-
commercial	2	34 ±9	-	-	-	
6. ARSENIC:						
residential	5	24 ±10		-	+	-
arterial	3	16 ±6	-		+	-
industrial	2	40 ±9	+	+		-
commercial	2	23 ±8	-	-	-	
7. CADMIUM:						
residential	5	1.0 ±0.4		-	-	-
arterial	3	0.67 ±0.02	-		-	+
industrial	2	1.4 ±0.8	-	-		-
commercial	2	1.2 ±0.1	-	+	-	
8. BERYLLIUM:						
residential	5	0.30 ±0.07		+	-	-
arterial	3	0.18 ±0.01	+		+	+
industrial	2	0.30 ±0.007	-	+		+
commercial	2	0.26 ±0.007	-	+	+	

Table 34. RANKING OF SIX METALS WITH HIGHEST CONCENTRATIONS IN STORMWATER AND STREET DUST SAMPLES.
(Metro Toxicant Inventory Data)
(All values are in ppm)

Stormwater			Street Dust		
element	mean	(sd)	element	mean	(sd)
Lead	0.21	(±0.16)	Lead	520	(±440)
Zinc	0.12	(±0.08)	Zinc	310	(±220)
Copper	0.02	(±0.01)	Chromium	97	(±69)
Arsenic	0.013	(±0.012)	Copper	93	(±70)
Nickel	0.012	(±0.004)	Nickel	32	(±7)
Chromium	0.007	(±0.005)	Arsenic	25	(±11)

Table 35. METALS IN STREET DUST FROM THREE LAND-USE TYPES--A COMPARISON OF NATIONAL WITH LOCAL DATA. Bradford (1977) data are from twelve studies. The confidence or degree of variability of the means is expressed as a range of percent standard error[a]. Mean concentrations are in mg/kg=ppm.

	Bradford (1977)						Metro's Toxicant Inventory Data					
	Res.		Comm.		Ind.		Res.		Comm.		Ind.	
Metal	mean	(%s.e.)	mean	(%s.e.)	mean	(%s.e.)	mean	(%s.e.)	mean	(%s.e.)	mean	(%s.e.)
Cadmium	3.0	a	4.2	b	4.0	c	1.0	b	1.2	a	1.4	d
Chromium	192	a	225	b	288	d	66	d	140	f	50	b
Copper	93	a	133	b	128	b	49	b	130	e	120	c
Nickel	28	b	48	b	41	d	26	a	34	b	36	c
Lead	1430	b	3440	b	2780	d	570	e	1000	a	460	b
Zinc	350	b	520	b	368	b	210	a	260	b	540	f

[a] Since Bradford (1977) data were only in this form, Metro's data were converted as follows:

Percent standard error = $100\left[\frac{Sd/n}{mean}\right]$; the code presents ranges:

a=0-9, b=10-19, c=20-29, d=30-39, 3=40-49, f=50+.

Table 36. COMPARISON OF METAL CONCENTRATIONS IN STREET DUST FROM THREE LAND-USE TYPES

Data are from studies by Pitt and Amy (1973) and Metro, and are expressed as average concentrations (± standard deviation) in mg/kg=ppm.

Metal	Pitt and Amy (1973)						Metro Toxicant Inventory (Seattle/Bellevue)		
	Nationwide (8 cities)			Seattle only					
	Res.	Comm.	Ind.	Res.	Comm.	Ind.	Res.	Comm.	Ind.
Cadmium	3.1(2.5)	5.1(5.6)	4.1(3.1)	1.6(1.4)	1.9(0.6)	1.4	1.0(0.4)	1.2(0.1)	1.4(0.8)
Chromium	190(71)	220(100)	270(160)	244(10)	256(13)	239	66(50)	140(130)	50(13)
Copper	92(41)	160(186)	110(62)	74(22)	140(100)	110	49(18)	130(86)	120(47)
Nickel	30(31)	50(50)	38(37)	37(5)	40(0.7)	20	26(4)	34(9)	36(11)
Lead	1600(1600)	3600(2500)	1700(2100)	2400(500)	4000(1000)	1100	570(510)	1000(85)	460(110)
Zinc	360(180)	520(240)	350(190)	500(110)	450(80)	480	210(40)	260(71)	540(608)

Table 37. METAL CONCENTRATIONS FOR STREET SWEEPINGS FROM LODI, NEW JERSEY

Data are mean concentrations in mg/kg=ppm for dust less than 63 microns; no standard deviation values were presented or calculable using the data supplied. (Wilber and Hunter, 1979.)

Land-use	Lead	Zinc	Copper	Nickel	Chromium
Residential	2110	464	75	36	43
Industrial	2520	2580	3170	9840	1450

Table 38. METALS IN STREET DUST FROM THE CENTRAL DISTRICT OF WASHINGTON, D.C.

Mean concentrations are in mg/kg=ppm. (Shaheen, 1975.)

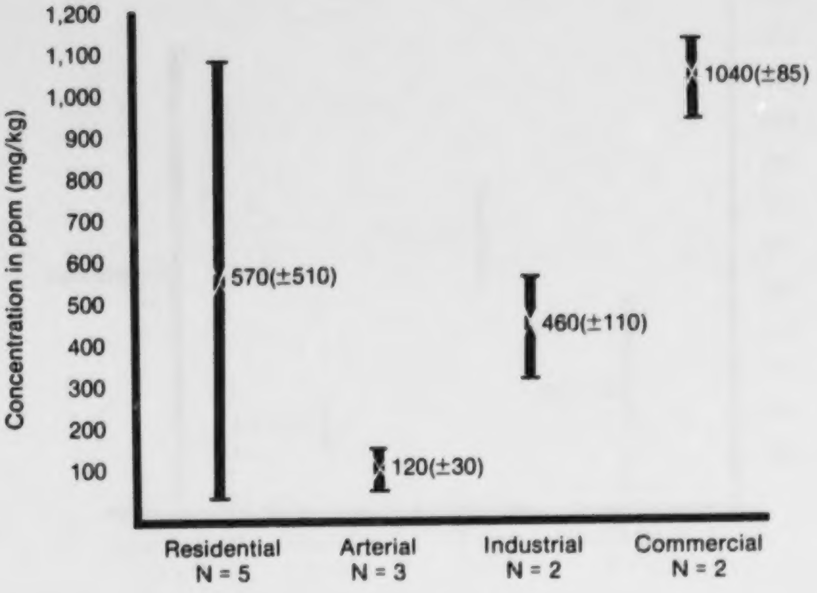
Metal	n	mean	(sd)
lead	118	4320	(±4370)
zinc	111	1110	(±1070)
copper	116	140	(±323)
nickel	117	121	(±73)
chromium	118	80	(±51)
cadmium	78	2.9	(±2.4)

Table 39. COMPARISON OF METAL
ANALYSES OF COMMERCIAL ARTERIAL STREET
DUST BETWEEN URBANA, ILL., AND METRO'S TOXICANT INVENTORY DATA
Hopke et al. (1980). Metro's data are from commercial and
suburban arterial samples.

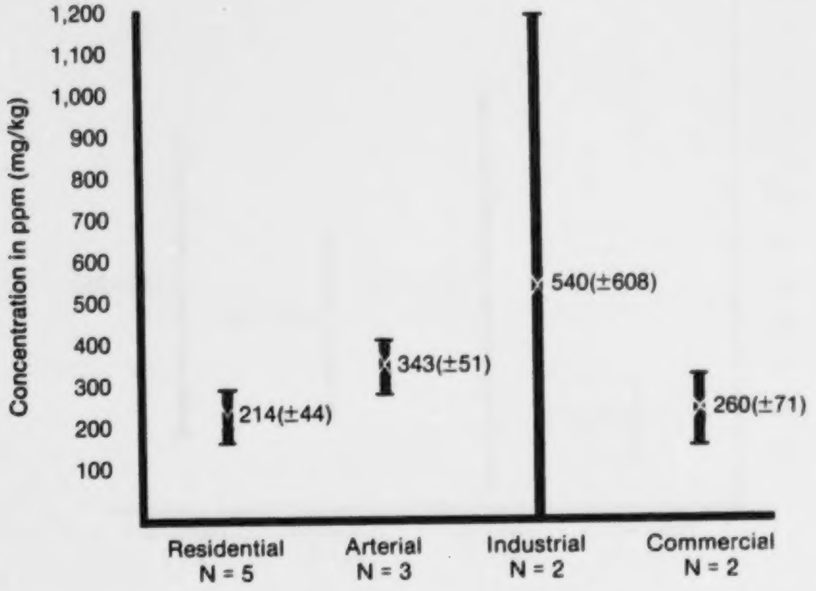
Metal	Urbana		Metro	
	mean	(sd)	mean	(sd)
Antimony	2.2	(±0.3)	1.0	(±0.2)
Arsenic	11	(± 1)	19	(±7)
Cadmium	1.6	(±0.2)	0.9	(±0.3)
Chromium	210	(±20)	150	(±70)
Lead	1000	(±200)	540	(±470)
Mercury	0.09	(±0.008)	0.06	(±0.04)
Nickel	250	(±60)	36	(±6)
Selenium	1.0	(±0.3)	<0.6	(±
Silver	0.2	(±0.09)	0.08	(±0.08)
Zinc	320	(±30)	310	(±70)

Table 40. COMPARISON OF METAL CONCENTRATIONS OF RESIDENTIAL
ROAD DUST BETWEEN SEATTLE AND BELLEVUE, WA.
Data are average concentrations (± stan. dev.) in mg/kg=ppm.
Seattle data are from Baily (1981). Bellevue data are from
Metro's Toxicant Inventory.

Metal	City of Seattle				City of Bellevue (Surrey Downs and Lake Hills)
	North Park	South Park	sig. diff.	Pooled	
	n=8	n=11	(p=.05)	n=19	n=5
Cadmium	4.6 (±2.1)	9.0 (±14)	no	7.2 (±11)	1.0 (±0.4)
Copper	100 (±43)	160 (±90)	yes	-	49 (±18)
Lead	1500 (±1800)	580 (±390)	no	970 (±1300)	570 (±510)
Nickel	65 (±41)	66 (±35)	no	65 (±36)	26 (±4)
Silver	10 (±10)	14 (±8)	no	12 (±9)	-
Zinc	270 (±230)	360 (±230)	no	320 (±230)	214 (±44)



A. LEAD

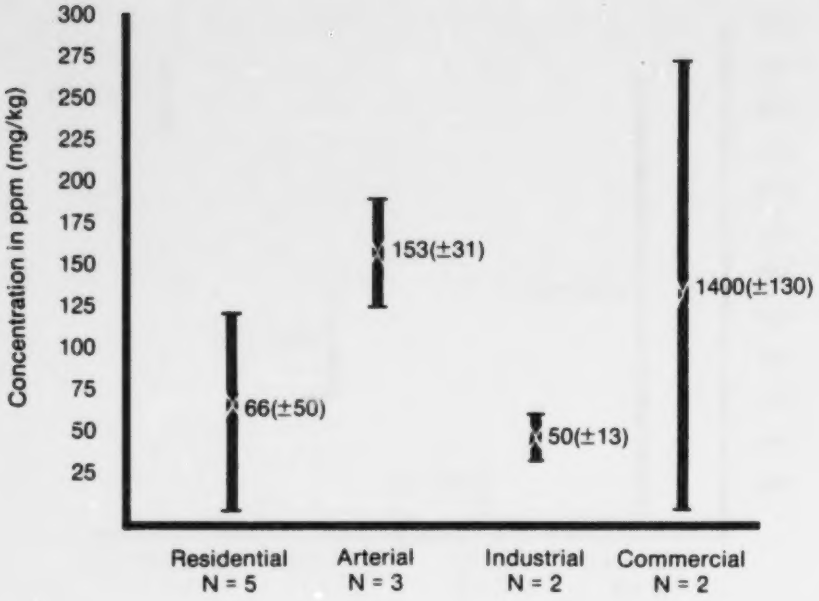


B. ZINC

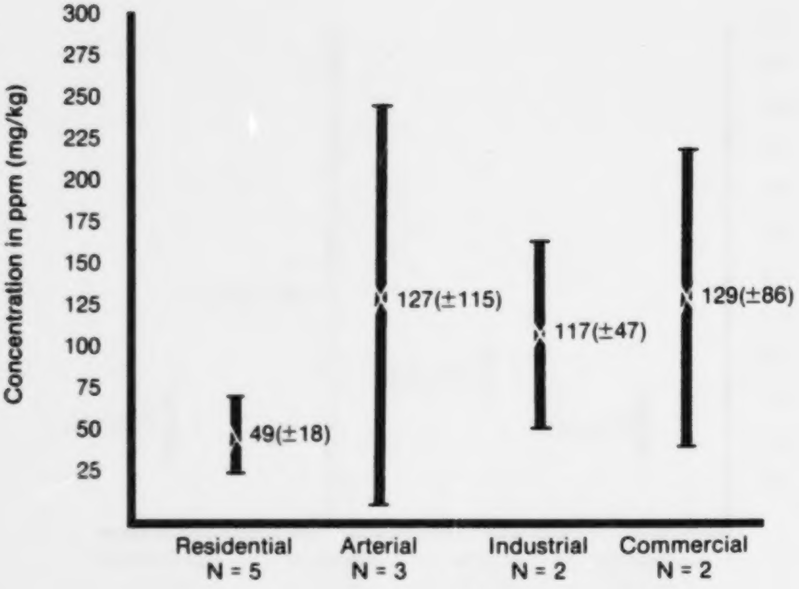
Figure 12.

METALS IN STREET DUST FROM DIFFERENT LAND-USE TYPES
(Metro Toxicant Inventory Data)

Bars show plus and minus one standard deviation.



B. COPPER



C. CHROMIUM

Figure 12. (Cont.)

METALS IN STREET DUST FROM DIFFERENT LAND-USE TYPES
(Metro Toxicant Inventory Data)

Bars show plus and minus one standard deviation.

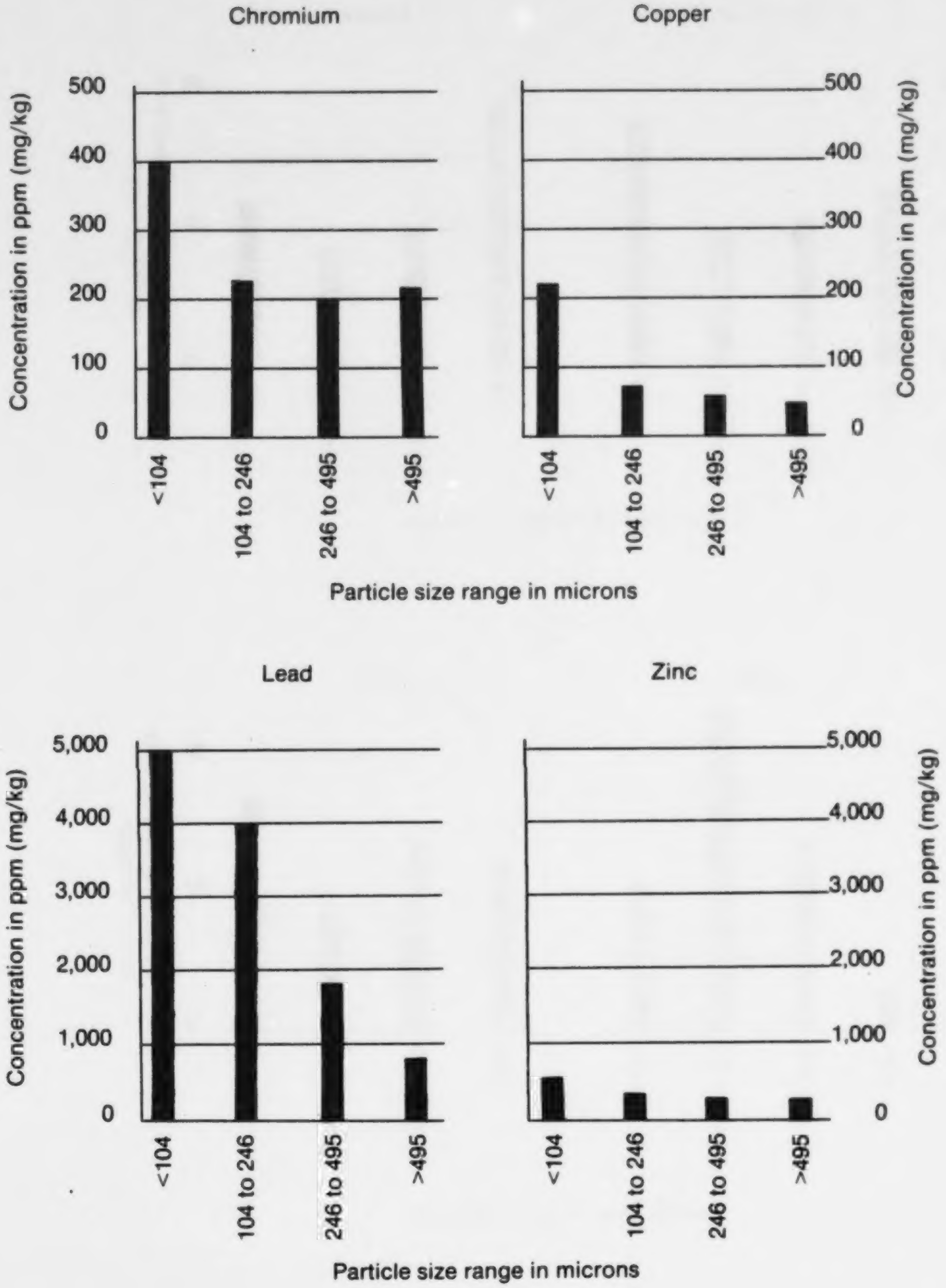


Figure 13.

CONCENTRATIONS OF FOUR METALS IN STREET DUST FROM SEATTLE BY PARTICLE-SIZE RANGES

Values are mean concentrations (no stan. dev. available) in ppm (mg/kg). (Pitt and Amy, 1973.)

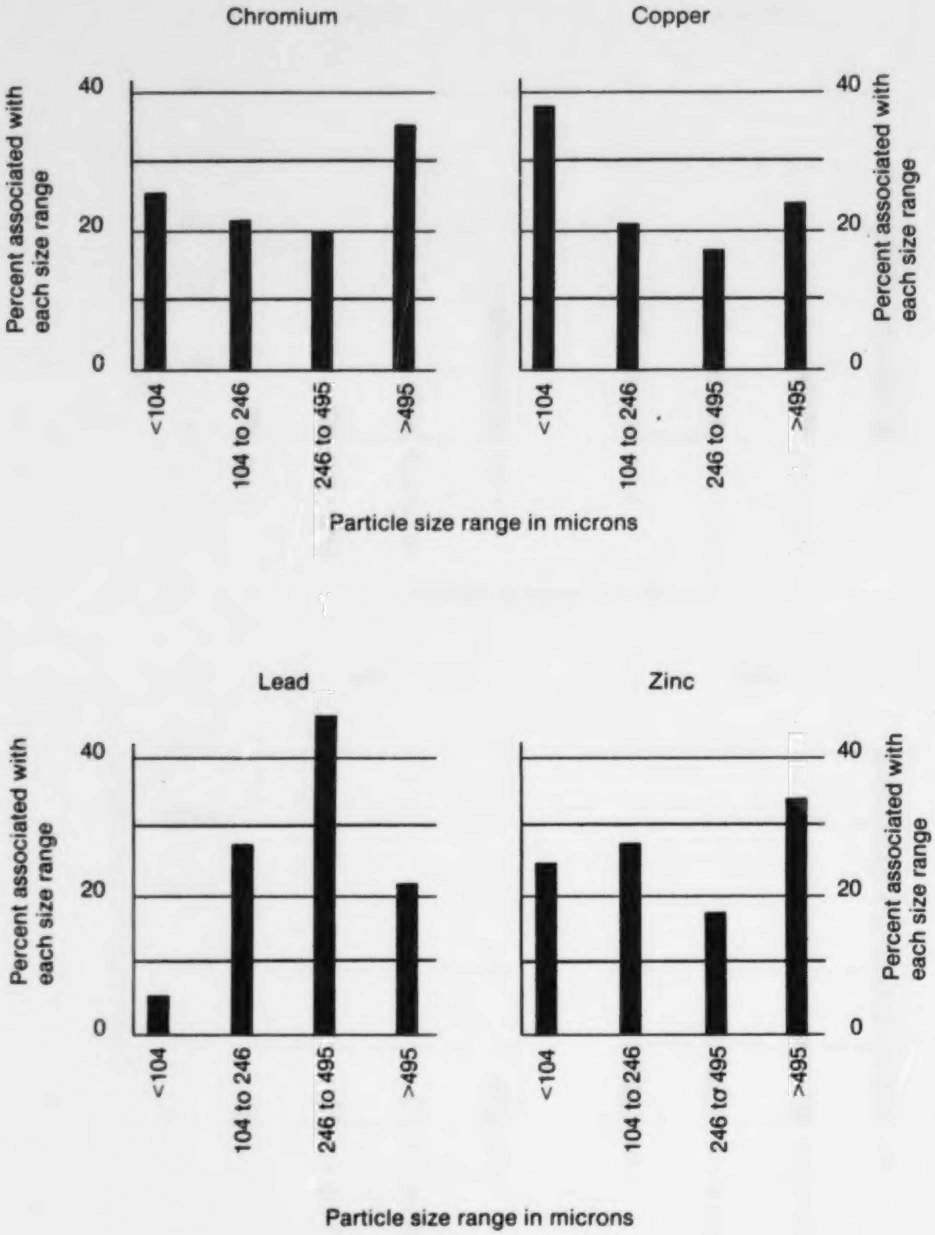


Figure 14.

DISTRIBUTION OF FOUR METALS AMONG PARTICLE-SIZE RANGES IN STREET DUST FROM SEATTLE
(Pitt and Amy, 1973)

In percentages by weight.

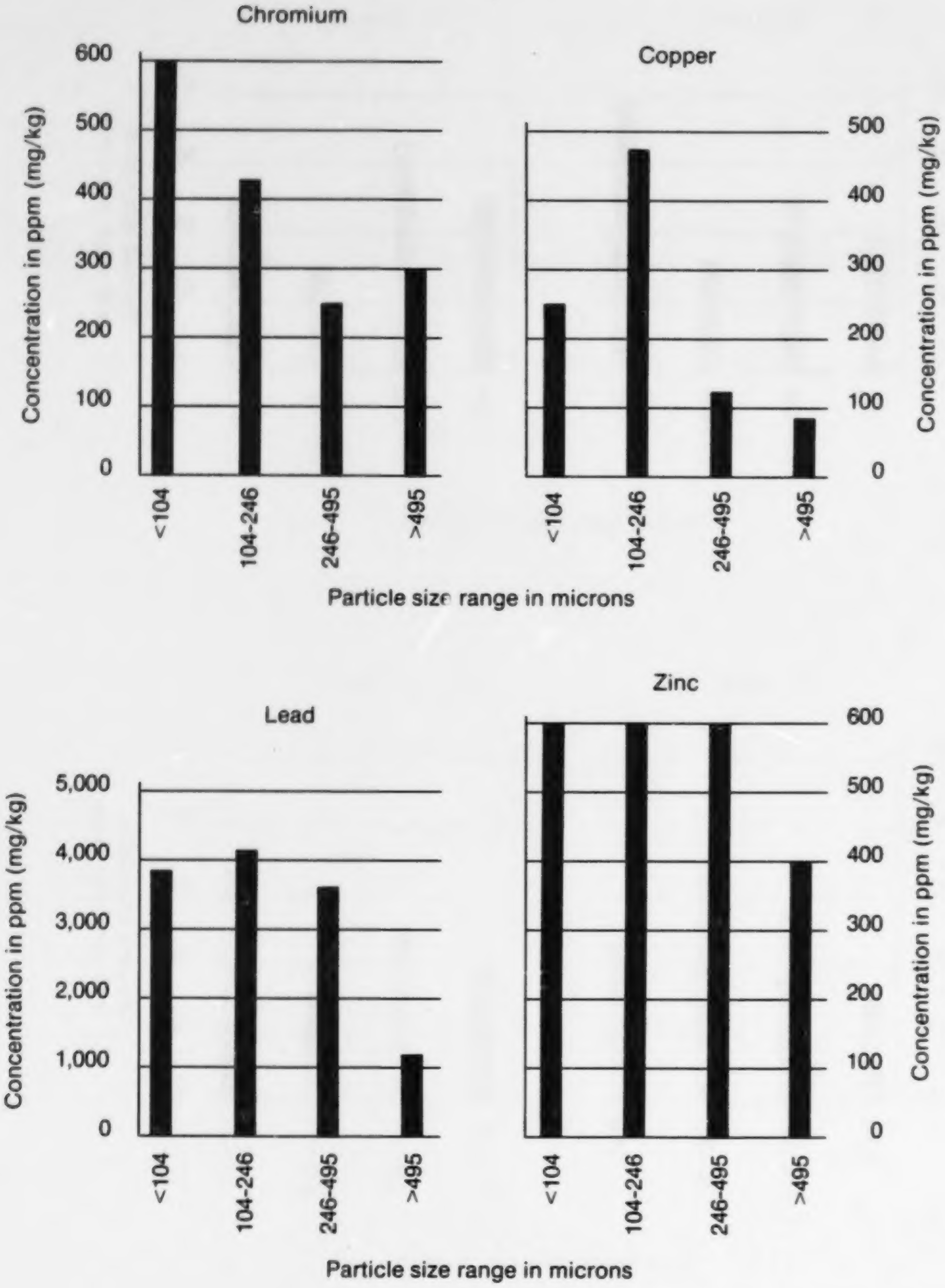


Figure 15.

CONCENTRATIONS OF FOUR METALS IN STREET DUST FROM FOUR CITIES BY PARTICLE-SIZE RANGES (Pitt and Amy, 1973)

Values are mean concentrations in ppm (mg/kg).

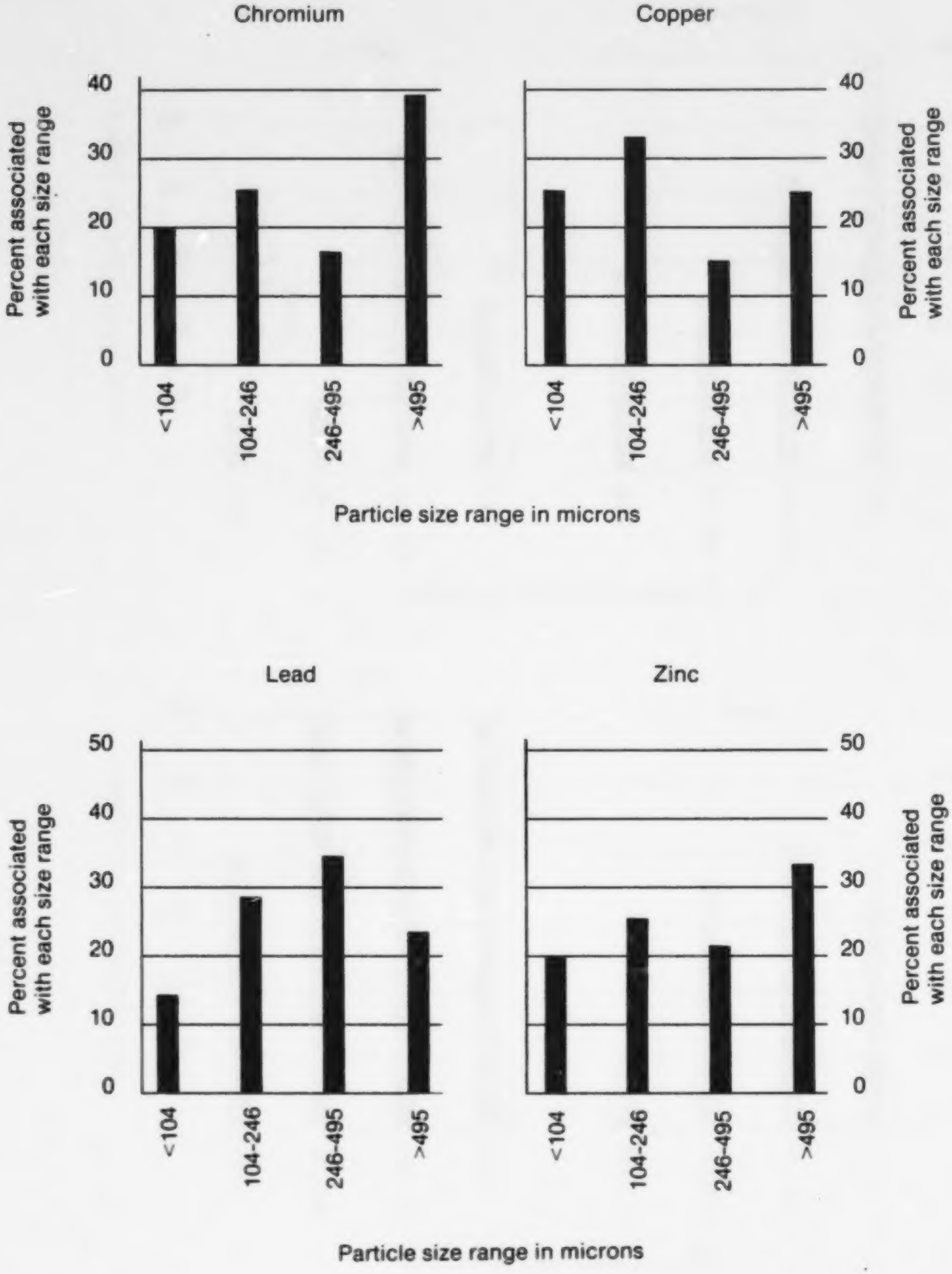


Figure 16.

DISTRIBUTION OF FOUR METALS AMONG PARTICLE-SIZE RANGES IN STREET DUST FROM FOUR CITIES (Pitt and Amy, 1973)

In percentages by weight.

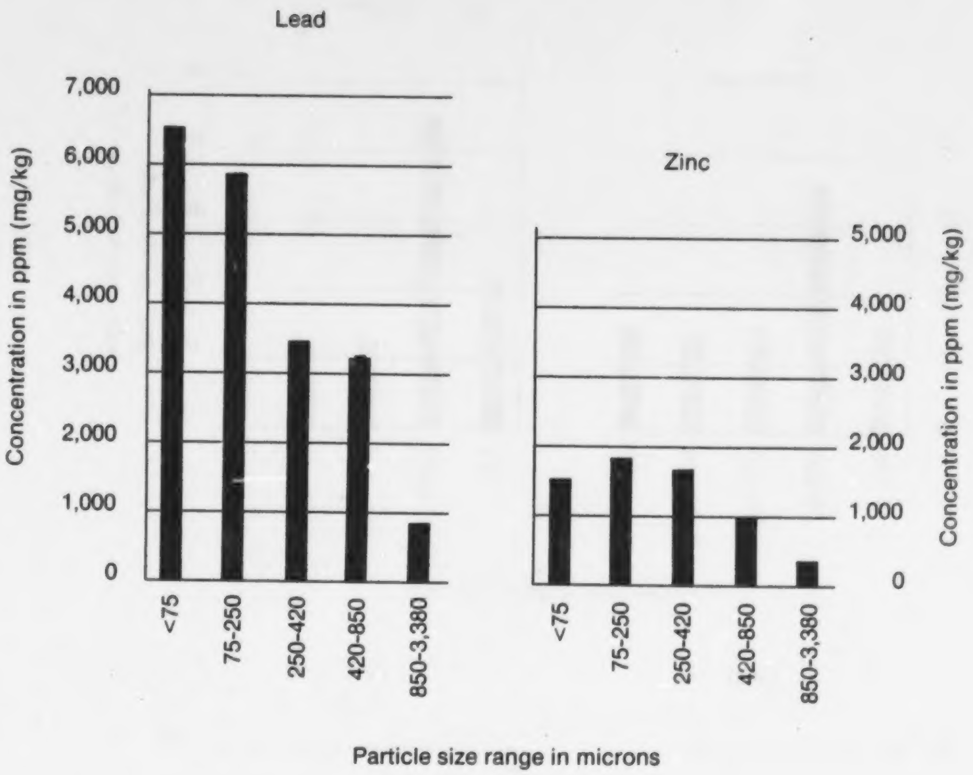


Figure 17.

CONCENTRATIONS OF TWO METALS IN STREET DUST FROM WASHINGTON, D.C. BY PARTICLE-SIZE RANGES (Shaheen, 1975)

Values are mean concentrations in ppm (mg/kg).

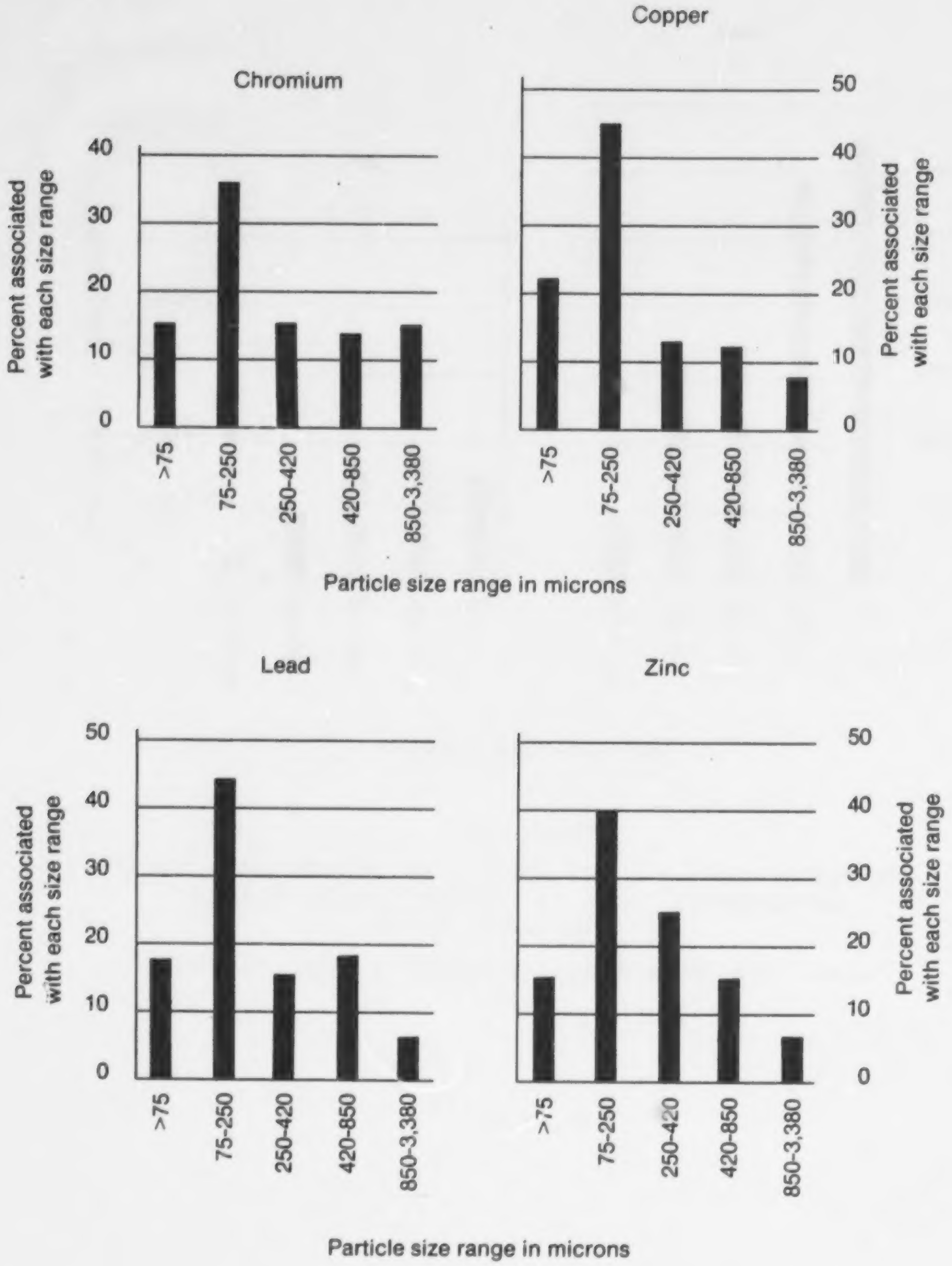


Figure 18.

DISTRIBUTION OF FOUR METALS AMONG PARTICLE-SIZE RANGES IN STREET DUST FROM WASHINGTON, D.C. (Shaheen, 1975)

In percentages by weight.

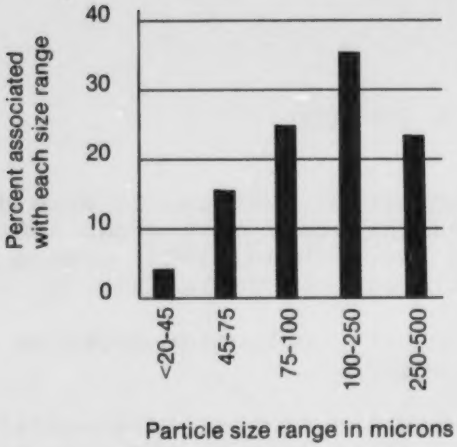


Figure 19.

DISTRIBUTION OF LEAD AMONG PARTICLE-SIZE RANGES IN COMMERCIAL/ARTERIAL STREET DUST FROM URBANA, ILLINOIS (Hopke et al., 1980)

In percentages by weight.

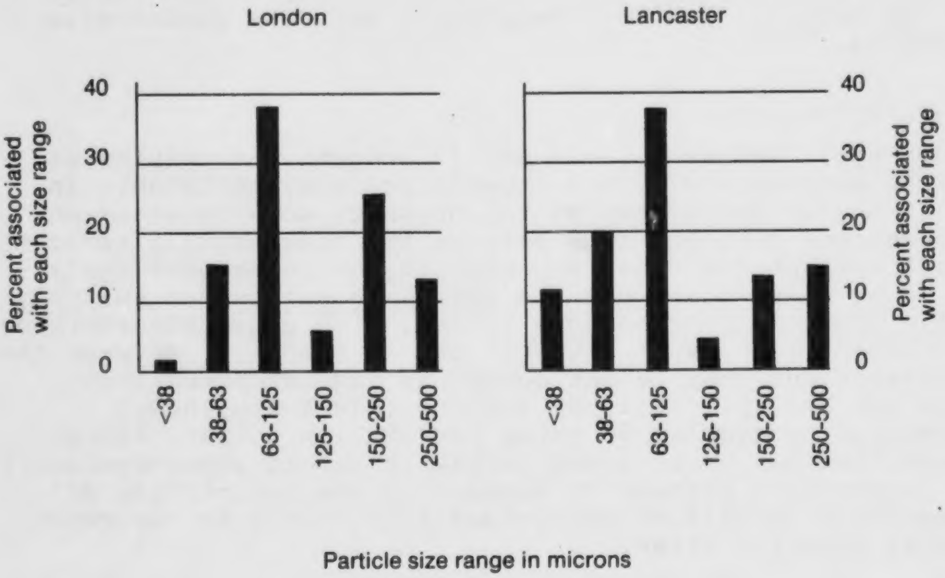


Figure 20.

DISTRIBUTION OF LEAD AMONG PARTICLE-SIZE RANGES IN COMMERCIAL/ARTERIAL STREET DUST

Samples are from London and Lancaster, England (Biggens and Harrison, 1980)

In percentages by weight.

(b) The Organic Toxicants. (Tables and figures for this subsection begin on page 3-65.)

SUMMARY

- Of the 111 organic priority pollutants, 32 were detected in the street dust samples analyzed; most often seen were the PAHs (fluoranthene and phenanthrene 100%; pyrene 93%; chrysene 79%) and the phthalates (see Table 43).
- Nearly twice as many priority pollutant organics appear in street dust as in stormwater.
- Those compounds seen with the highest frequencies and concentrations in street dust tend to be the same as those seen in stormwater (dilution probably accounts for the low number of detectable organics in stormwater). (See Table 45.)
- Few other studies have been done on organics in street dust and those focused on the pesticides and PCBs.
- The reports describing the relationship between organics and particle size support the same relationship as that noted for the metals: most are associated with the finest-size fractions.

- Occurrence. Tables 41, 42, and 43 present the results of Metro's examination of the organic priority pollutants in street dust. Thirty-two of the organics were detected and at least one compound from each of the nine organic toxicant groups (except the PCBs) appeared in the 14 samples analyzed. Most often seen were the phthalate esters and the polycyclic aromatic hydrocarbons (PAHs). Two PAHs, fluoranthene and phenanthrene, were found in all 14 samples. Between the phthalates and PAHs, eight compounds had concentrations above one part per million, and one (bis-2-ethylhexyl phthalate) as high as 90 parts per million. (This latter observation may be at least partially due to contamination.) One interesting pattern to appear was the restriction of tentatively identified pesticides exclusively to the residential sampling sites.

  Dust samples were reviewed for non-priority pollutant organic compounds. The tentative (unconfirmed) results are presented in Table 44. All of these compounds are also in the list in Table 25 from the highway runoff samples, but it should be remembered that these results are computer system "best fit" identifications without any critical review or confirmation. For example, various esters of benzenedicarboxylic acid appear in the Table 25 list and were assigned a "best fit" in most of the Metro samples, but Acurex and Metro chemists conclude that such an identification is due to phthalate contamination.

- Comparison With Metro's Stormwater Organics. Nearly twice as many priority pollutant organics appear in street dusts as in stormwater (see Table 45).

  Comparing occurrences of compounds from the various chemical groups, one finds nine of the PAHs in street dust also appeared in stormwater. Only one of the six phthalates was detected in stormwater, but it was not one of those frequently found at high concentrations in road dust. While four of the volatile aromatics were seen in street dusts, only one, benzene, appeared in stormwaters. Examining the pesticides, endosulfan tentatively occurred once in stormwater but not at all in the street dust samples.

- Comparison With the Literature. While the literature has stated that "significant amounts" of hazardous organic compounds are present in street dust (Sartor and Boyd, 1972; Jacksim and Lake, 1978; Novotny and Chesters, 1981), very few published data are available to verify these conclusions. Where concentration values can be found, they include only the pesticides and polychlorinated biphenyls.

  One of the early projects to examine organics in dust was conducted by Sartor and Boyd (1972), who focused on the persistent chlorinated hydrocarbons, specifically PCBs and the pesticides DDT, its derivative DDD, dieldrin, endrin, and lindane. Table 46 presents average street dust concentrations from eight U.S. cities, including Seattle. A comparison with Metro data indicates much lower DDD concentrations and higher lindane concentrations in the recent local samples. Some or all of this variability may be inherent in the GC/ECD protocols which can yield false identifications (Farlow, personal communication). Figure 21 presents the variation of three pesticides and total PCBs by particle-size class in Sartor and Boyd's samples.

  Sartor and Boyd (1972) found no consistent patterns in higher or lower pesticide concentrations by landuse type, but did detect many pesticides in commercial and industrial as well as residential areas. This contrasts with the pattern seen in the Metro data showing detectable concentrations of pesticides only in residential dust samples.

  Shaheen (1975) analyzed 12 street dust samples for total PCBs and found an average concentration of 1.8 (± 1.3) ppm with a range of 0.5 - 3.6 ppm.

PAHs have received intense study in environmental samples in recent years, including some analyses of street dust. Review of the distribution of PAH types (low versus high molecular weight compounds) in street dust and runoff led Wakeham et al. (1980a) to speculate that the PAHs were coming more from wear of the asphalt road surfaces than from atmospheric fallout. But they admit that their "weathered asphalt" sample which matched the street dust profile may have reflected combustion-derived material adhered onto the asphalt particles. (Other authors, e.g., Blumer et al., (1977), Hase and Hites (1976), generally support combustion-related fallout as the primary PAH source.) Figure 22 presents Wakeham et al.'s (1980a) PAH profile in street dust.

Table 41. ORGANIC PRIORITY POLLUTANTS IN BELLEVUE RESIDENTIAL STREET DUST SAMPLES

(Metro Toxicant Inventory Data)
Data are concentrations in mg/kg=ppm.

	Occurrence	2-Surrey Downs 6/30-80 (Swept)	11-Surrey Downs 10/14/80	12-Surrey Downs Replicate of 11	32-Surrey Downs 7/28/81	3-Lake Hills 7/1/80	13-Lake Hills 10/13/80 (Swept)	34-Lake Hills 7/27/81	Mean[a]	Standard Deviation[a]
PESTICIDES:										
α - BHC	2/7			0.010			0.018		0.014	(±0.007)
γ - BHC (lindane)	2/7			0.006			0.043		0.024	(±0.026)
DDD	1/7		0.005						0.005	--
Heptachlor	1/7						0.048		0.048	--
HALOGENATED ALIPHATICS:										
Trichloromethane	4/7		0.005	0.004	0.015		0.004		0.004	(±0.002)
Tetrachloroethene	2/7	0.032				0.016			0.024	(±0.011)
1,1,1-Trichloroethane	0/7								--	--
4-Chlorophenyl phenyl ether	1/7					0.24			0.24	--
MONOCYCLIC AROMATICS:										
Benzene	0/7								--	--
Hexachlorobenzene	1/7							2.0	2.0	--
Ethylbenzene	3/7	0.005	0.005	0.025					0.012	(±0.012)
Toluene	3/7		0.004	0.008		0.005			0.006	(±0.002)
N-nitrosodimethylamine	0/7								--	--
PHENOLICS:										
Phenol	3/7	0.1				0.08		0.47	0.22	(±0.22)
Pentachlorophenol	2/7	3.4				0.12			1.8	(±2.3)
2,4-Dimethylphenol	2/7	0.01				0.03			0.02	(±0.01)
4-Nitrophenol	1/7					0.11			0.11	--
PHTHALATE ESTERS:										
Dimethyl phthalate	1/7							0.78	0.78	--
Diethyl phthalate	3/7	0.16				0.18		0.89	0.41	(±0.42)
Di-n-butyl phthalate	3/7	0.52				2.4		0.49	1.14	(±1.09)
Di-n-octyl phthalate	1/7							0.97	0.97	--
Butyl-benzyl phthalate	4/7	0.68			1.0	0.22		35	3.5	(±19)
Bis-2 ethylhexyl phthalate	3/7	24			20	11			18.3	(±6.7)

Table 41 (Continued). ORGANIC PRIORITY POLLUTANTS IN BELLEVUE RESIDENTIAL STREET DUST SAMPLES (Metro Toxicant Inventory Data)

(ppm=mg/kg)	Occurrence	2-Surrey Downs 6/30/80 (Swept*)	11-Surrey Downs 10/14/80	12-Surrey Downs Replicate of 11	32-Surrey Downs 7/28/81	3-Lake Hills 7/1/80	13-Lake Hills 10/13/80 (Swept*)	34-Lake Hills 7/27/81	Mean[a]	Standard Deviation[a]
PAHs:										
Acenaphthene	1/7						0.16		0.16	--
Anthracene	2/7						0.24	0.29	0.26	(±0.04)
Benzo(a)anthracene	1/7							0.66	0.66	--
Benzo(k)fluoranthene	3/7	0.28			1.4			1.4	1.0	(±0.65)
Benzo(a)pyrene	2/7	0.08						0.64	0.36	(±0.40)
Chrysene	5/7	0.34			1.0	0.21	2.0	1.1	0.68	(±0.41)
Fluorene	1/7						0.2		0.2	--
Phenanthrene	7/7	0.32	0.64	0.88	1.8	0.18	1.7	1.9	1.1	(±0.73)
Pyrene	6/7	0.44		1.0	1.7	0.32	2.4	2	1.2	(±0.53)
Fluoranthene	7/7	1.1	0.78	1.2	1.8	0.74	2.6	2.2	1.5	(±0.72)

[a] Mean and standard deviation values for the organics are calculated using all values for compounds found 100% of the time, by Aitcheson's delta distribution (see Appendix B) for compounds found >50% but <100% of the time, and using observed values only for compounds found < 50% of the time; the means for the latter group will tend to be artificially high, as they are means of observations only, not total number of samples.

Table 42. ORGANIC PRIORITY POLLUTANTS IN ARTERIAL, COMMERCIAL AND INDUSTRIAL STREET DUST SAMPLES
(Metro Toxicant Inventory Data)
Data are concentrations in mg/kg = ppm.

	Suburban Arterial					Commercial				Industrial			
	33-148th St. 6/25/81	30-148th St. 8/6/81	31-148th St. Replicate of 30	Mean^a	(SD)^a	58-3rd Ave CBD 3/18/82	59-Elliott Ave 3/18/82	Mean^a	(SD)^a	57-4th S. & Mich. 3/18/82	60-4th Ave. S. Replicate of 57	Mean^a	(SD)^a
PESTICIDES:													
α-BHC													
γ-BHC (lindane)													
DDD													
Heptachlor													
HALOGENATED ALIPHATICS:													
Trichloromethane													
Tetrachloroethene													
1,1,1-Trichloroethane						0.012	0.012	.012	0		0.016		
4-Chlorophenyl phenyl ether													
MONOCYCLIC AROMATICS:													
Benzene			0.032							0.01			
Hexachlorobenzene													
Ethylbenzene													
Toluene						0.019							
N-nitrosodimethylamine											0.76		
PHENOLICS:													
Phenol			0.2										
Pentachlorophenol													
2,4-Dimethylphenol													
4-Nitrophenol													
PHTHALATE ESTERS:													
Dimethyl phthalate													
Diethyl phthalate													
Di-n-butyl phthalate	0.22	0.49	0.57	0.43	0.18		2.2						
Di-n-octyl phthalate	0.23	0.7	0.27	0.4	0.3								
Butyl-benzyl phthalate	2.1	2.5	2.2	2.3	0.2								
Bis-2 ethylhexyl phthalate	2.4		43	15	24	41^b	90^b	66^b	35	33^b	74^b	54^b	29

Table 42 (Continued). ORGANIC PRIORITY POLLUTANTS IN ARTERIAL, COMMERCIAL AND INDUSTRIAL STREET DUST SAMPLES (Metro's Toxicant Inventory Data)

	Suburban Arterial					Commercial				Industrial			
(ppm=mg/kg)	33-140th St. 6/25/81	30-140th St. 8/6/81	31-140th St. Replicate of 30	Mean[a]	(SD)[a]	58-3rd Ave CBD 3/18/82	59-Elliott Ave 3/18/82	Mean[a]	(SD)[a]	57-4th S. & Mich. 3/18/82	60-4th Ave. S. Replicate of 57	Mean[a]	(SD)[a]
PAHs:													
Acenaphthene	0.25												
Anthracene	0.6	0.32	0.32	0.4	0.1								
Benzo(a)anthracene	0.68	0.24	0.55	.46	.20	0.78				0.66	0.85	0.76	.13
Benzo(k)fluoranthene	1.5	0.27	1.3	1.0	.66	1.5				1.2			
Benzo(a)pyrene	0.75	0.45	0.9	0.7	0.2	0.90				0.69			
Chrysene	1.1	1.2	0.98	1.1	.11	1.3				1.0	1.3	1.2	.21
Fluorene	0.25												
Phenanthrene	2.3	1.5	1.5	1.8	.46	2.4	1.2	1.8	.85	1.9	2.6	2.2	.50
Pyrene	2.1	1.5	1.6	1.7	.32	2.5	1.6	2.0	.64	1.9	2.5	2.2	.42
Fluoranthene	2.2	1.5	1.7	1.8	.36	2.5	1.5	2.0	.71	1.9	2.2	2.0	.21

[a] Mean and standard deviation values for the organics are calculated using all values for compounds found 100% of the time, by Aitcheson's delta distribution (see Appendix B) for compounds found >50% but <100% of the time, and using observed values only for compounds found <50% of the time; the means for the latter group will tend to be artificially high, as they are means of observations only, not total number of samples.

[b] Method blank for samples #56-60 showed BEHP contamination or false positive at 280 ppb, which was high compared to other method blanks (see Appendix A) and may indicate contamination with the sediment values reported.

Table 43. SUMMARY OF ORGANIC PRIORITY POLLUTANTS IN STREET DUST SAMPLES
(Metro Toxicant Inventory Data)
Data are concentrations in mg/kg = ppm.

	Residential		Suburban Arterial		Commercial		Industrial		Totals			
	Occurrence	Mean[a]	Occurrence	Mean[a]	Occurrence	Mean[a]	Occurrence	Mean[a]	Occurrence	(%)	Mean[a]	Standard Deviation[a]
PESTICIDES:												
α-BHC	2/7	0.014	0/3	--	0/2	--	0/2	--	2/14	(14%)	0.014	(±0.00)
γ-BHC (lindane)	2/7	0.024	0/3	--	0/2	--	0/2	--	2/14	(14%)	0.024	(±0.02)
DDD	1/7	0.005	0/3	--	0/2	--	0/2	--	1/14	(07%)	0.005	--
Heptachlor	1/7	0.048	0/3	--	0/2	--	0/2	--	1/14	(07%)	0.048	--
HALOGENATED ALIPHATICS:												
Trichloromethane	4/7	0.004	0/3	--	0/2	--	0/2	--	4/14	(29%)	0.004	(±0.00)
Tetrachloroethene	2/7	0.024	0/3	--	0/2	--	0/2	--	2/14	(14%)	0.024	(±0.01)
1,1,1-Trichloroethane	0/7	--	0/3	--	2/2	0.012	1/2	0.016	3/14	(21%)	0.013	(±0.00)
4-Chlorophenyl phenyl ether	1/7	0.24	0/3	--	0/2	--	0/2	--	1/14	(07%)	0.24	--
MONOCYCLIC AROMATICS:												
Benzene	0/7	--	1/3	0.032	0/2	--	1/2	0.01	2/14	(14%)	0.021	(±0.02)
Hexachlorobenzene	1/7	2.0	0/3	--	0/2	--	0/2	--	1/14	(07%)	2.0	--
Ethylbenzene	3/7	0.012	0/3	--	0/2	--	0/2	--	3/14	(21%)	0.012	(±0.01)
Toluene	3/7	0.006	0/3	--	1/2	0.019	0/2	--	4/14	(29%)	0.009	(±0.00)
N-nitrosodimethylamine	0/7	--	0/3	--	0/2	--	1/2	0.76	1/14	(07%)	0.76	--
PHENOLICS:												
Phenol	3/7	0.22	1/3	0.2	0/2	--	0/2	--	4/14	(29%)	0.21	(±0.18)
Pentachlorophenol	2/7	1.8	0/3	--	0/2	--	0/2	--	2/14	(14%)	1.8	(±2.3)
2,4-Dimethylphenol	2/7	0.02	0/3	--	0/2	--	0/2	--	2/14	(14%)	0.02	(±0.01)
4-Nitrophenol	1/7	0.11	0/3	--	0/2	--	0/2	--	1/14	(07%)	0.11	--
PHTHALATE ESTERS:												
Dimethyl phthalate	1/7	0.78	0/3	--	0/2	--	0/2	--	1/14	(07%)	0.78	--
Diethyl phthalate	3/7	0.41	0/3	--	0/2	--	0/2	--	3/14	(21%)	0.41	(±0.42)
Di-n-butyl phthalate	3/7	1.14	3/3	0.43	1/2	2.2	0/2	--	7/14	(50%)	0.98	(±0.91)
Di-n-octyl phthalate	1/7	0.97	3/3	0.4	0/2	--	0/2	--	4/14	(29%)	0.54	(±0.36)
Butyl-benzyl phthalate	4/7	3.5	3/3	2.3	0/2	--	0/2	--	7/14	(50%)	6.2	(±13)
Bis-2 ethylhexyl phthalate	3/7	18	2/3	15	2/2	66	2/2	54	9/14	(64%)	38	(±29)
PAHs:												
Acenaphthene	1/7	0.16	1/3	0.25	0/2	--	0/2	--	2/14	(14%)	0.20	(±0.06)
Anthracene	2/7	0.26	3/3	0.4	0/2	--	0/2	--	5/14	(36%)	0.36	(±0.14)
Benzo(a)anthracene	1/7	0.66	3/3	0.46	1/2	0.78	2/2	0.76	7/14	(50%)	0.63	(±0.20)
Benzo(k)fluoranthene	3/7	1.0	3/3	1.0	1/2	1.5	1/2	1.2	8/14	(57%)	0.67	(±0.26)
Benzo(a)pyrene	2/7	0.36	3/3	0.7	1/2	0.90	1/2	0.69	7/14	(50%)	0.63	(±0.29)
Chrysene	5/7	0.68	3/3	1.1	1/2	1.3	2/2	1.2	11/14	(79%)	0.86	(±0.22)
Fluorene	1/7	0.2	1/3	0.25	0/2	--	0/2	--	2/14	(14%)	0.22	(±0.04)
Phenanthrene	7/7	1.1	3/3	1.8	2/2	1.8	2/2	2.2	14/14	(100%)	1.5	(±0.76)
Pyrene	6/7	1.2	3/3	1.7	2/2	2.0	2/2	2.2	13/14	(93%)	1.6	(±0.35)
Fluoranthene	7/7	1.5	3/3	1.8	2/2	2.0	2/2	2.0	14/14	(100%)	1.7	(±0.60)

[a] Mean and standard deviation values for the organics are calculated using all values for compounds found 100% of the time, by Aitcheson's delta distribution (see Appendix C) for compounds found >50% but <100% of the time, and using observed values only for compounds found <50% of the time; the means for the latter group will tend to be artificially high, as they are means of observations only, not total number of samples.

Table 44. TENTATIVE IDENTIFICATIONS OF NON-PRIORITY POLLUTANT ORGANICS IN STREET DUST SAMPLES

(Metro Toxicant Inventory Data)

Extra searches were conducted on sample nos. 30-34 and 57-61.

ORGANIC COMPOUND	OBSERVATIONS/ TOTAL NO. SEARCHES	PROBABLE ORIGIN[a]
2-Ethyl-hexanol	2/10	Soaps, detergents, biogenic
2-Methyl-1-pentene	1/10	Biogenic, gasoline
9-Methyl-phenanthrene	1/10	Biogenic, pyrolysis
2-Methyl-phenanthrene	1/10	Motor oil, pyrolysis
4-Methyl-2-pentanone	3/10	Biogenic
Octadecanoic acid	1/10	Biogenic
Hexadecanoic acid	2/10	Biogenic
1,3-Isobenzofurandione	1/10	Petroleum, pyrolysis
Heneicosane	1/10	Biogenic
Thio(bis)methane	1/10	Biogenic
Dimethyl-disulfide	1/10	Biogenic
Hexatriacontane	3/10	Biogenic
Eicosane	1/10	Biogenic
Pentacosane	1/10	Biogenic
Hexadecene	1/10	Oxidation of paraffins
Hexadien-3-yne	3/10	Oxidation of paraffins

[a] Farlow (pers. comm.).

Table 45. RANKING OF THE MOST COMMONLY SEEN ORGANICS IN STORMWATER AND STREET DUST SAMPLES
(Metro Toxicant Inventory Data)

Compounds listed in order by frequency of occurrence, first in stormwater >10%, then others in dust to ≥50%. Concentrations are in ppb = μg/l for water or μg/kg for dust.

	Stormwater			Street Dust		
	Freq. Occur.	Conc. ppb (sd)		Freq. Occur.	Conc. ppb (sd)	
Fluoranthene	4/21	4	(± 5)	14/14	1,700	(±610)
Phenanthrene	4/21	2	(± 3)	14/14	1,500	(±750)
Pyrene	4/21	5	(± 4)	13/14	1,700	(±710)
Pentachlorophenol	4/21	34	(± 54)	2/14	1,800	(±2,300)
Chrysene	3/21	2	(± 1)	11/14	1,000	(±480)
Dieldrin	3/21	0.04	(± 0.05)	0/14	--	--
Bis-2-ethyl hexyl phthalate	0/21	--	--	9/14	37,600	(±29,000)
Benzo(k) fluoranthene	1/21	4	--	8/14	1,100	(±520)
Butyl benzyl phthalate	0/21	--	--	7/14	6,200	(±13,000)
Di-n-butyl phthalate	0/21	--	--	7/14	980	(±910)
Benzo(a) anthracene	0/21	--	--	7/14	630	(±200)
Benzo(a) pyrene	0/21	--	--	7/14	630	(±290)

Table 46. PESTICIDES AND PCBs IN URBAN STREET DUST SAMPLES

The data from eight U.S. cities are from Sartor and Boyd (1972) and Amy et al. (1974). All concentrations are in ug/kg = ppb.

Compound	Average from 8 cities		Metro data	
	mean	(sd)	mean	(sd)
α-BHC	--	--	14	(7)
γ-BHC (lindane)	2.9	(7.1)	24	(26)
endrin	0.2	--	--	--
DDD	82	(78)	5	--
DDT	76	(118)	--	--
dieldrin	28	(28)	--	--
heptachlor	--	--	48	--
methoxychlor	500	(1050)	--	--
methyl parathion	2	--	--	--
PCB (total)	770	(770)	--	--

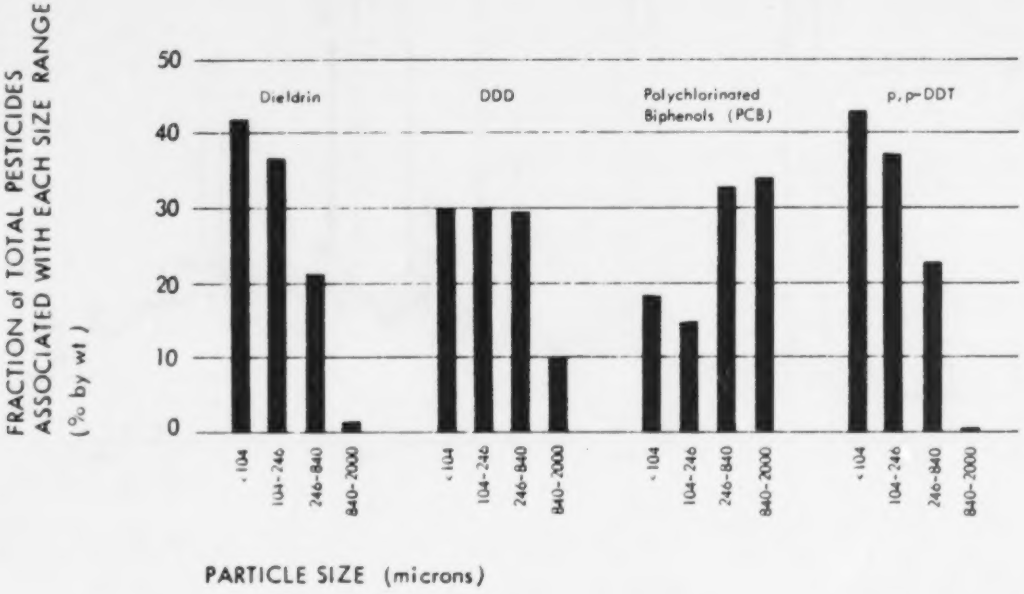
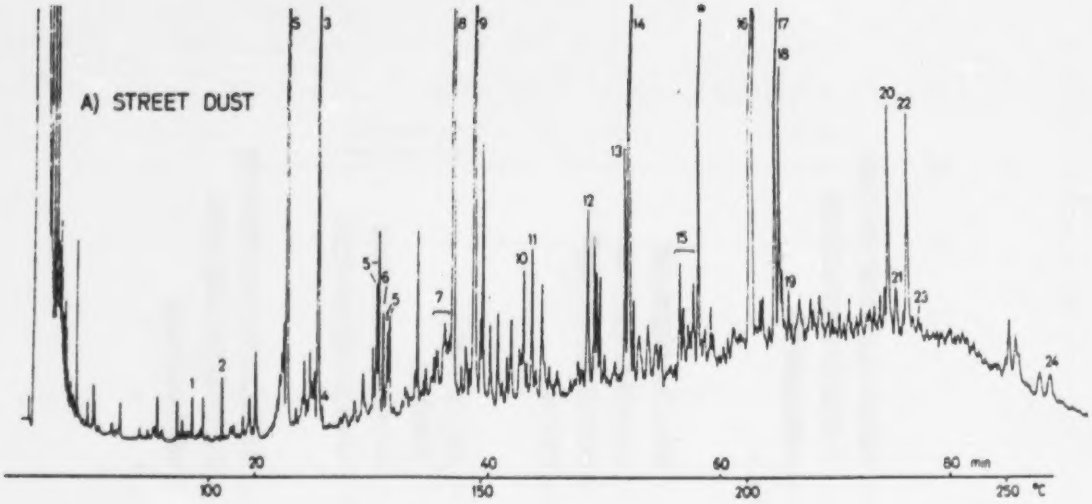


Figure 21.

DISTRIBUTION OF PESTICIDES AND PCBs AMONG PARTICLE-SIZE RANGES IN STREET DUST FROM EIGHT CITIES (Sartor and Boyd, 1972)

In percentages by weight.



Peak Number	Compound
1	Acenaphthene
2	Fluorene
3	Phenanthrene
4	Anthracene
5	Methylphenanthrenes[a]
6	4,5-Methylenephenanthrene
7	Dimethyl/ethylphenanthrenes
8	Fluoranthene
9	Pyrene
10	1,2-Benzofluorene
11	2,3/3,4-Benzofluorenes
12	1,2-Benzofluoranthene
13	1,2-Benzanthracene
14	Chrysene/triphenylene
15	Methylchrysenes
16	Benzofluoranthenes
17	1,2-Benzopyrene
18	3,4-Benzopyrene
19	Perylene
20	Indeno (1,2,3-cd)pyrene
21	1,2,3,4/1,2,5,6-Dibenzanthracenes
22	1,12-Benzoperylene
23	Anthanthrene
24	Coronene
S	Internal Standard

Figure 22.

PAHs IN STREET DUST

Capillary gas chromatogram is from Wakeham et al. (1980a).

2. Atmospheric Suspended Particles

(Review limitations described in the Study Design section, pages 2-5.)

(a) The Metals. (Tables for this subsection begin on page 3-77.)

SUMMARY

- The constituents of material that settles as dustfall are not necessarily the same as those of atmospheric suspended particles.
- Of the 11 inorganic toxicants detected on the filters, the six with the highest dry weight concentrations were zinc, lead, copper, arsenic, nickel, and chromium.

- Occurrence. The analysis of two separate sets of high-volume air filters for suspended air particles resulted in two distinctly different sets of data, as can be seen in Table 47. The first group of 40 filters (sample #39) contained 11 of the 14 priority pollutant inorganics; only beryllium, thallium, and the cyanides were not detected. The six metals with the highest concentrations were, in descending order, zinc, lead, copper, arsenic, nickel and chromium. The ranking of high concentration toxicants varied between air particle sample #39 and the road dust. Table 48 compares the six leading metals in each.

  The second set of ten air filters (sample #56) was from a recent period of winter air conditions. This set contained the same 11 metals found in sample #39 in essentially the same ranking (Table 48), but they appeared at only one-tenth the concentrations of the older sample.

- Comparison With the Literature. In the only comparable data we could find on metals in local suspended air particles, Hardy and Crecelius (1981) found the following in high-volume filters at the University of Washington campus (in ppm): arsenic 1,400; copper 950; lead 179,000; and zinc 1,980. Crecelius (1975) analyzed high-volume filters for arsenic in his study of Lake Washington and reported a mean of 1,640 ppm during a south wind, but a mean of only 170 ppm during a north wind. He attributed the high arsenic concentrations to the exhaust plume from the Ruston/Tacoma ASARCO smelter.

Most of the literature's data on air particles were based on annual dryfall loadings rather than average ambient concentrations. One study was found which could be compared with Metro values; it was conducted in New York City between 1969 and 1975 by Kleinman et al. (1980). Table 49 presents their figures for six of the toxic metals (for comparison, Metro values were converted to nanograms of pollutant per cubic meter of filtered air). A comparison shows that while Seattle's 1976 concentrations are very similar to New York's, the Seattle 1981 concentrations are only one-tenth as high.

Dustfall is considered a significant contributor to street dirt and stormwater contamination (Sartor and Boyd, 1972; Novotny and Chesters, 1981). Heany and Sullivan (1971) attributed 70% of Chicago's street dirt to accumulated dustfall. Pitt, in the Bellevue Urban Runoff Project's First Annual Report, states, "In heavily urbanized areas, dustfall can contribute more of an annual load than the wet precipitation, especially when dustfall includes resuspended materials" (Pitt et al., 1981).

Table 47. CONCENTRATIONS OF METALS ON HIGH-VOLUME AIR FILTERS FROM THE DUWAMISH VALLEY, SEATTLE

Values are concentrations in mg/kg = ppm in suspended air particles. Sample #39 was a composite of 40 filters collected between January and October 1976. Sample #56 was a composite of 10 filters collected in December 1981.

Toxic Metal	Sample #39	Sample #56
Antimony	56	1.9
Arsenic	360	51
Beryllium	---	---
Cadmium	23	2.5
Chromium	180	15
Copper	950	60
Lead	1,700	390
Mercury	6	0.39
Nickel	200	21
Selenium	45	1.4
Silver	4.2	0.69
Thallium	---	---
Zinc	3,100	140
Cyanides	---	---

Table 48. COMPARISON OF SIX METALS WITH THE HIGHEST CONCENTRATIONS IN AIRBORNE PARTICULATE MATTER, STREET DUST, AND STORMWATER All values are concentrations in ppm.

Air Particulates							
#39		#56		Street Dust		Stormwater	
ranking	conc.	ranking	conc.	ranking	conc.	ranking	conc.
zinc	3100	lead	390	lead	520±440	lead	0.21±.16
lead	1700	zinc	140	zinc	310±220	zinc	0.12±.08
copper	950	copper	60	chromium	97±69	copper	0.02±.01
arsenic	360	arsenic	51	copper	93±70	arsenic	0.013±0.012
nickel	200	nickel	21	nickel	32±7	nickel	0.012±0.004
chromium	180	chromium	15	arsenic	25±11	chromium	0.007±0.005

Table 49. CONCENTRATIONS OF METALS WITH SUSPENDED AIR PARTICLES FROM NEW YORK CITY AND METRO'S TOXICANT INVENTORY DATA
All values are concentrations in ng/m^3. Metro data were converted from mg/kg particulate based upon quantity of air passed through filter. New York data are from Kleinman et al. (1980).

Metal	New York City			Seattle	
	NYU Medical Center-1975	Bronx 1973	Queens 1975	1976	1981
Cadmium	4.2	3.5	1.9	1.7	0.19
Chromium	8.5	5.3	3.2	14.0	1.1
Copper	43.9	52.5	22.3	71.0	4.5
Lead	107.0	1580.0	707.0	130.0	29.0
Nickel	35.2	311.0	7.8	15.0	1.6
Zinc	294.0	284.0	181.0	230.0	11.0

(b) The Organic Compounds. (Tables for this subsection begin on page 3-82.)

SUMMARY

- The polycyclic aromatic hydrocarbons (PAHs) comprised the majority of organic compounds detected on the filters.
- The molecular structure of these PAHs suggests that they originate with petroleum pyrolysis.

- Occurrence. Table 50 lists the organic priority pollutants and their concentrations found in the two air filter sample groups. While several phthalates were noted, their presence as contaminants in the blank filters makes their values unreliable. The polycyclic aromatic hydrocarbons comprised the majority of compounds detected in each sample. Table 51 presents the PAH data with the street dust results for comparison. It is interesting to note that the ranking of PAHs in these two sample types is quite different; although there is much overlap in the identified compounds, the higher molecular weight (four- to six-ring) PAHs are dominant by weight in the airborne particulate matter, while the lower molecular weight (two- to three-ring) PAHs are dominant in the dust. This suggests that airborne PAHs are combustion products, while street dust PAHs are from petroleum spillage.

  Pentachlorophenol and 4-nitrophenol are also notable in their occurrence and concentrations in the 1981 air sample. Both have also been detected in street dust samples.

- Comparison With the Literature. Other than information on occupational exposures inside industrial buildings, the literature on organic compounds in the air deals almost exclusively with PAHs.

  As products of combustion, PAHs tend to be ubiquitous but highly correlated with human activity (Neff, 1979). PAHs appear to be closely associated with airborne particulate matter, although the lower molecular weight compounds (e.g., phenanthrene, fluoranthene, pyrene) are more often found in the "vapor phase" and are less particle-bound than the higher weight compounds (e.g., benzo(a)pyrene, benzo(ghi)perylene) (Wakeham *et al*., 1980; Cautreels and VanCauwenberghe, 1976a, 1976b, 1978). PAHs that are particle-bound tend to be associated with very small soot particles ≤ one micron (Neff, 1979; Pedersen *et al*., 1980; Thomas *et al*., 1968).

Concentrations of PAHs expressed as a fraction of the total particulate mass are seldom reported. Gordon (1976), in a study around Los Angeles, California, found total PAH concentrations of about 50 mg/kg or ppm (range: 41-62 ppm), with the concentration of benzo(a)pyrene at 5.24 ppm. These values are comparable to the Metro data.

Concentrations of PAHs expressed per unit volume of air (e.g., ng/m^3) are more widespread. Gordon's (1976) data for eight PAHs are compared with the local Metro data (converted) in Table 52. U.S. EPA (1975) data for benzo(a)pyrene measured in 139 urban stations in 1970 averaged 2.62 ng/m^3 (range: 0.2-29.5), while results from non-urban stations averaged 0.23 ng/m^3 (range: 0.1-2.1). These sample values indicate a general reduction in airborne organics over the measured time intervals.

In a less specific local analysis, Wakeham (1977) measured aliphatic hydrocarbons in dustfall in his study of organic loadings into Lake Washington. He found levels ranging from 2,200 to 10,200 mg/kg (ppm) in the dustfall, which he attributed to petroleum organics. Metro's Toxicant Inventory samples support this generalization -- most airborne organics appear to result from petroleum product combustion.

Table 50. CONCENTRATIONS OF ORGANIC COMPOUNDS ON HIGH-VOLUME AIR FILTERS FROM THE DUWAMISH VALLEY, SEATTLE
(Metro Toxicant Inventory Data)
Values are concentrations in µg/kg = ppb. Sample #39 was a composite of 40 filters, sample #56 was a composite of 10 filters.
(ND = Not Detected).

	1976 sample		1981 sample	
Organic Compound	Sample #39	(Blank)	Sample #56	(Blank)
4,4'-DDE	ND	(ND)	4.6	(ND)
Endosulfan Sulfate	ND	↓	25.0	↓
Endrin	ND		12.0	
Pentachlorophenol	ND		1,700	
4-nitrophenol	ND		2,300	
Bis(2-ethylhexyl) phthalate	89,000	(62,000)	4,900	
Butylbenzyl phthalate	13,000	(43,000)	ND	
Di-n-butyl phthalate	40,000	(64,000)	1,200	
Di-n-octyl phthalate	3,000	(ND)	ND	
Diethyl phthalate	22,000	↓	ND	
Phenanthrene	2,000		ND	
Fluoranthene	ND		720	
Pyrene	4,000		1,400	
Benzo(a)anthracene	7,000		1,900	
Chrysene	9,000		1,400	
Benzo(k)fluoranthene	12,000		4,200	
Benzo(a)pyrene	3,000		1,700	
Indeno(1,2,3-cd)pyrene	17,000		720	
Benzo(ghi)perylene	ND		3,700	

Table 51. COMPARISON BETWEEN PAHs IN SUSPENDED AIR PARTICLES AND IN STREET DUST
(Metro Toxicant Inventory Data)

All values are concentrations in ppm = mg/kg. PAH are listed in order from low to high molecular weight.

	Air Particles		Street Dust	
	1981	1976	mean	(±2.d.)
Acenaphthene	--	--	0.20	(±.06)
Fluorene	--	--	0.22	(±.04)
Phenanthrene	--	2.0	1.5	(±.76)
Anthracene	--	--	0.36	(±.14)
Fluoranthene	0.72	--	1.7	(±.60)
Pyrene	1.4	4.0	1.6	(±.35)
Benzo(a)anthracene	1.9	7.0	0.63	(±.20)
Benzo(k)fluoranthene	4.2	12.0	0.67	(±.26)
Benzo(a)pyrene	1.7	3.0	0.63	(±.29)
Indeno(1,2,3-cd) pyrene	0.73	17.0	--	
Benzo(ghi)perylene	3.7	--	--	

Table 52. CONCENTRATIONS OF PAHs ON ATMOSPHERIC SUSPENDED PARTICLES FROM LOS ANGELES AND SEATTLE. All values are air concentrations in ng/m^3. Metro data were converted from mg/kg particulate based upon quantity of air passed through filter. Los Angeles data are yearly geometric means from a large number of stations and samples from Gordon (1976). PAHs are listed in order from low to high molecular weight.

	Los Angeles	Seattle	
	1976	1976	1981
Fluoranthene	0.31	----	0.05
Pyrene	0.45	0.30	0.10
Benzo(a)anthracene	0.18	0.52	0.14
Chrysene	0.60	0.68	0.10
Benzo(k)fluoranthene	0.20	0.90	0.32
Benzo(a)pyrene	0.46	0.22	0.13
Indeno (1,2,3-cd) pyrene	1.34	1.28	0.05
Benzo(ghi)perylene	3.27	----	0.28

3. Catchbasin Sediments and Base Flows

(Tables begin on page 3-87.)

SUMMARY

- Most inorganic and organic toxicants had similar concentrations in both the control structure sediments and the street dust.
- The exceptions were lead (higher in the sediments) and chromium and copper (higher in the street dust).
- Base flow samples contained high copper and zinc concentrations but no detectable organics, suggesting infiltration from the public water supply.

- Occurrence. As described in the section on sampling procedures, Metro examined sediment from the stormwater control structure serving the detention basin at 148th Street SE in Bellevue -- a potential contributor of priority pollutant materials to stormwater. Sartor and Boyd (1972) point out that fine particulate solids deposited during previous storms are often stirred up and swept out of catchbasins by the first-flush action of the next storm, adding to its stormwater contaminant levels.

  Table 53 lists the toxic metal and organic concentrations in the catchment sediment and compares them with those seen in local street dust samples. Most of the elements and compounds were observed at similar concentrations in the two sample types. Lead, however, appeared at a concentration much higher in the detention basin than in the street dust, while chromium and copper were much lower; zinc, the other major street runoff metal, was comparable between the two. These findings do not seem to be explained by a review of the particle-size distributions of the two sample types, and may be an artifact of sampling or analysis.

  During the dry periods between storms, both the Surrey Downs and Lake Hills storm drains produced steady, low-volume flows of water, or base flows. These were sampled and analyzed in order to determine their contributions to stormwater toxicant concentrations. Table 54 presents these data, as well as the corresponding composite stormwater concentrations for comparison. Except for very high concentrations of copper and zinc, base flow concentrations were lower than stormwater values. No organics were detected in either base flow sample.

The high copper and zinc concentrations suggest contamination from copper and galvanized (zinc) water pipes. A study by the Seattle Water Department (Courchene *et al.*, 1978) reported maximum concentrations of copper and zinc found in the public water supply system of 1,600 and 2,600 parts per billion, respectively, both much higher than any other trace metal detected in the system.

- *Comparison With the Literature*. In reviewing the available literature on toxicants and nonpoint pollution, no data were found on concentrations observed in either stormwater detention basin sediments or base flows.

Table 53.
TOXICANT CONCENTRATIONS IN STORMWATER CONTROL STRUCTURE SEDIMENT COMPARED WITH THOSE IN STREET DUST
(Metro Toxicant Inventory Data)

Metals and organics data are presented as concentrations in ppm=mg/kg dry weight. Less than (<) values indicate detection limits (for metals); N.D.=Not detected (for organics).

Toxicant	148th Ave. S.E. Sediment Mar. '82	148th Ave. S.E. Street Dust Aug. '81
(Inorganics)		
Antimony	1.3	1.1
Arsenic	19.0	16.0
Beryllium	0.19	0.18
Cadmium	1.4	0.67
Chromium	20	150
Copper	35	130
Lead	600	120
Mercury	0.11	0.10
Nickel	20	38
Selenium	<0.6	<3
Silver	0.08	<0.5
Thallium	<0.2	<1
Zinc	310	340
Cyanides	0.18	0.4
(Organics)		
Fluoranthene	2.5	1.8
Benzo(a)anthracene	1.1	0.46
Chrysene	2.0	1.1
Phenanthrene	2.1	1.8
Pyrene	3.0	1.7
Toluene	0.12	N.D.
α-BHC	0.00045	N.D.
β-BHC	0.00019	N.D.
δ-BHC	0.00042	N.D.

TABLE 54. TOXICANT CONCENTRATIONS IN STORM DRAIN BASE FLOWS COMPARED WITH THOSE IN STORMWATER FROM LAKE HILLS AND SURREY DOWNS (Metro Toxicant Inventory Data)

Values are concentrations in parts per billion = μg/l.

Toxicant	Surrey Downs		Lake Hills	
	Base Flow March, 1982	Stormwater mean	Base Flow March, 1982	Stormwater mean
(Inorganics)				
Antimony	<1	<3	<1	<3
Arsenic	<2	16	2	10
Beryllium	<0.1	<0.3	<0.1	<0.3
Cadmium	0.4	0.64	0.5	0.7
Chromium	2	8.1	1	6.8
Copper	1200	21	1300	18
Lead	64	230	67	190
Mercury	<0.5	<1	<0.5	<1
Nickel	7	16	<7	15
Selenium	<2	<2	<2	<2
Silver	<0.5	0.6	<0.5	0.8
Thallium	<1	<1	<1	<1
Zinc	830	130	850	100
Cyanides	<5	<10	13	20
(Organics)				
None Detected				

4. Other Significant Sources Cited in the Literature

(Tables for this subsection begin on page 3-93.)

SUMMARY

Urban Soils

- Because urban soils trap many of the toxicants which contact them, they in turn become potential sources of stormwater contamination.

- Average background concentrations as high as 5 ppm for the combined PAHs may be common in soils worldwide -- the result of historic human use of fossil fuels.

- Natural background concentrations of some trace metals in Puget Sound soils and rocks resemble concentrations in street dust samples; exceptions include high lead, zinc, copper, and arsenic levels in the dust.

Petroleum from Motor Vehicles

- Spillage produces noticeable oily coatings on road and parking surfaces.

- Both new and used petroleum products contain significant amounts of the inorganic as well as organic toxicants, and may represent the major source of many of these substances to runoff.

Atmospheric Wet Precipitation

- While rain and snow can remove significant amounts of the larger atmospheric suspended particles, sampled concentrations of trace metals in stormwater tend to be 20 to 30 times greater than in rainfall.

Road Surfacing Materials

- Yellow lane-striping paint contains chromium pigments.

- Asphalt particles are composed of very heavy organic compounds and may trap the organic toxicants, especially the pyrolytic PAHs.

Miscellaneous

- Tire wear particles can represent up to 7% by weight of street dust, and are reported to contain high concentrations of zinc and lead oxides.

- Brake lining wear is a primary source of copper and a contributing source for chromium and nickel to street dust metal concentrations.

(a) Urban Soils. While urban soils are usually covered by some sort of impervious surface or vegetative cover, they can be exposed during construction and are rapidly eroded by wind and water. A study done in 1971 under the Urban Soils Monitoring Program (Carey et al., 1979) examined the levels of arsenic, pesticides, and PCB's in the soils of five U.S. cities. Table 55 presents these figures. These urban soil concentrations are generally of the same magnitude as the toxicant concentrations found in street dust.

Blumer et al. (1977), in their study of PAHs in soils and sediments, found total PAH concentrations as high as 300 mg/kg (ppm) in Swiss urban soils near highways, with concentrations dropping to 5 - 10 ppm in open country soils away from highways. They concluded that values around 5 ppm "may well represent a worldwide PAH background," while the elevated concentrations in urban soils, especially in close proximity to highways, represent internal combustion engine products.

Concentrations of trace metals for Puget Sound soils and for average earth's crust are listed in Table 56. A comparison of these values with Metro street dust data shows that, except for lead, zinc, copper and arsenic, which are elevated in the street dust (to as much a 40 times for lead), the background soils and street dust concentrations are of approximately the same magnitudes.

(b) Petroleum from Motor Vehicles. Lubricant, hydraulic fluid, and fuel leaks from motor vehicles are very common and form noticeable coatings on urban streets and parking areas. These petroleum-based products contain significant amounts of both inorganic and organic toxicants. Shaheen (1975) analyzed used crankcase oil and found the following metal concentrations: zinc at 1,100 mg/kg (ppm), nickel at 17 mg/kg, lead at 9 mg/kg, and copper at 3 mg/kg.

Many of the organic toxicants are present in the various petroleum compounds. Gasoline, for example, contains benzene, toluene, phenols, and polycyclic aromatics (Fristch, 1978). Most of the references dealing with general organic loads in runoff or street dust (e.g., Wakeham, 1976, 1977; Zawlocki, 1981; Hunter et al., 1979) point to lubricating ("crankcase" or "motor") oil as the major source. However, the dominant source of benzo(a)pyrene is the pyrolysis of diesel fuel (Farlow, personal communication). Table 57 lists levels of benzo(a)pyrene, a PAH, in gasoline and motor oil.

(c) Atmospheric Wet Precipitation. Rain and snow usually remove the larger suspended particles from the atmosphere at higher rates than dryfall; however, total loadings may be similar (Novotny and Chesters, 1981). Several factors can affect concentrations and produce wide variability: storm intensity and duration, time elapsed since previous storm, and distance to pollutant sources. Table 58 (from Wilber and Hunter, 1975) describes the concentrations of five trace metals in rainfall at Lodi, New Jersey. These values average 20 to 30 times less than the concentrations seen in the New Jersey stormwater runoff. Table 59 gives toxic metal concentrations found in rain and snow precipitation over northern Minnesota (from Eisenrich, 1981); except for lower concentrations of chromium and lead, values are similar to those from the Wilber and Hunter study.

(d) Road Surfacing Materials. The yellow paint used for lane striping has a chrome-yellow pigment at a concentration of 17% by weight, according to the Seattle Engineering Department.

Asphalt is made up of the heaviest liquid fractions from petroleum distillation and contains a wealth of complex organic chemicals. Wakeham et al. (1980) found that fresh asphalt contains a "complex mixture of PAH[s] in which few compounds actually predominate." Weathered asphalt, on the other hand, was found to match street dust and air particulate PAH patterns. They concluded that a major component of street dust and stormwater PAH load comes from road-wear (asphalt particles), although they admit that these PAHs may be from atmospheric dust and soot associated with the asphalt particles. Wallcave et al. (1971, as quoted in Neff, 1979) documented high concentrations of PAHs in asphalt, including a predominance of alkyl-substituted PAHs over unsubstituted compounds. However, benzo(a)pyrene concentrations (high-temperature pyrolysis) ranged from 0.1 to 27 ppm in the eight samples analyzed.

Asphalt pavement has been found to contain high metal concentrations as well. Shaheen (1975) determined the following concentrations: nickel at 1,170 ppm, chromium at 357 ppm, zinc at 164 ppm, lead at 102 ppm and copper at 51 ppm.

(e) Miscellaneous. The results of analyses of potential source materials by Shaheen (1975) are presented in Table 60.

Tire wear is often listed as a major source of certain contaminants to street surfaces. Hopke et al. (1980) concluded that much of the zinc, arsenic, cadmium and chromium in street dust is contributed by tire wear. They determined that 7.2% (by weight) of street dust is automobile tire wear particles, and that the concentration of zinc in rubber can range as high as 12,000 mg/kg (ppm). However, Shaheen's (1975) analysis (Table 60) found zinc concentrations in rubber of only 617 ppm, with lead nearly twice as high (1,110 ppm); rubber was found to be only 0.5% of total street dust. Wakeham et al. (1980) analyzed tire particles for PAHs and concluded that the PAH assemblage in the tire sample was quite different from that seen in the street dust, with a predominance of sulfur- and nitrogen-containing compounds. Most automobile tires in the U.S. are 70 to 80% styrene-butadiene rubber, with zinc and other metallic oxides used as "fillers" (Shaheen, 1975).

Brake linings are also often cited as a pollutant source, especially for copper. Shaheen (1975) suggests that brake linings are the major source of copper, and a contributing source of chromium and nickel. Hopke et al. (1980) substantiate this source for chromium but not nickel; they did not analyze for copper.

Table 55. MEAN ARSENIC AND PESTICIDE CONCENTRATIONS IN SOILS OF FIVE U.S. CITIES. Values are concentrations in ppm dry weight, from U.S. EPA's Urban Soils Monitoring Program (Carey et al., 1979).

Location	Arsenic	Aldrin	Dieldrin	Chlordane	Heptachlor	Heptachlor Epoxide
Baltimore, Md. 156 samples	7.1	0.02	0.02	0.21	ND*	<0.01
positive detection =	100%	2.6%	18.7%	36.8%		3.2%
Gadsden, Ala. 55 samples	7.8	ND*	<0.01	0.07	ND*	<0.01
positive detection =	100%		12.7%	5.1%		1.8%
Hartford, Conn. 19 samples	10.6	<0.01	0.06	4.00	<0.01	0.02
positive detection =	100%	8.3%	10.4%	47.9%	2.1%	14.6%
Macon, Ga. 43 samples	1.8	ND*	0.02	0.08	<0.01	<0.01
positive detection =	100%		30.2%	25.6%	4.6%	20.9%
Newport News, Va. 78 samples	2.4	ND*	0.04	0.16	<0.01	<0.01
positive detection =	92.3%		9.0%	12.8%	2.6%	3.8%

*ND=Not Detected

Table 55 (Continued). MEAN ARSENIC AND PESTICIDE CONCENTRATIONS IN SOILS OF FIVE U.S. CITIES.

Location	Endrin	Endrin Ketone	Endosulfan Sulfate	PCBs	Toxaphene	DDE	DDT
Baltimore, Md. 156 samples	ND*	ND*	<0.01	0.02	ND*	0.12	0.40
positive detection =			0.6%	3.9%		52.3	61.3%
Gadsden, Ala. 55 samples	ND*	ND*	ND*	0.22	ND*	0.04	0.12
positive detection =				1.8%		70.9%	70.9
Hartford Conn. 19 samples	ND*	ND*	ND*	ND*	ND*	0.17	0.56
positive detection =						79.2%	84.4
Macon, Ga. 43 samples	<0.01	<0.01	<0.01	ND*	0.24	0.10	0.37
positive detection =	2.3%	2.3%	2.3%		25.6	95.3%	97.7%
Newport News, Va. 78 samples	ND*	ND*	ND*	0.04	ND*	0.11	0.26
positive detection =				1.3%		60.3%	60.3%

*ND=Not Detected

Table 56. TRACE METAL COMPOSITION OF PUGET SOUND SOILS AND AVERAGE EARTH CRUST

Values are concentrations in ppm=mg/kg.

	Concentrations (ppm)				
	Puget Sound Soils		Earth's Crust		
Metal	(Ref. a)	(Ref. b)	(Ref. c)	(Ref. d)	(Ref. e)
Antimony	< 15	--	1	0.2-0.5	0.2
Arsenic	< 100	--	5	5	1.8
Beryllium	1	--	6	2.5	2.8
Cadmium	< 7	0.13	0.15	0.15	0.2
Chromium	80	--	200	10-100	100
Copper	20	5.4	70	50	55
Lead	15	9.8	16	--	12.5
Nickel	80	1.4	80	80	75
Silver	< 0.7	--	0.1	0.1	--
Zinc	80	21.8	132	123	--

References:

[a] Unpublished figures of D. Pevear, Geology Dept., Western Washington University, as reported in Dexter et al. (1981).

[b] PacForest soils, Horizon A--Everett Type, from Edmonds and Cole (1977).

[c] CRC Handbook of Chemistry and Physics, as cited in Dexter et al. (1981).

[d] Callahan et al. (1979).

[e] Jenkins (1981).

Table 57. CONCENTRATIONS OF BENZO(a)PYRENE IN PETROLEUM PRODUCTS

Values are average concentrations in ppm. (Neff, 1979.)

Material	Concentration (ppm)
Regular Gasoline	0.21
Premium Gasoline	0.48
New Motor Oil	0.28
Used Motor Oil	6.4

Table 58. CONCENTRATIONS OF METALS IN PRECIPITATION AND STORMWATER IN LODI, N.J. Values are mean concentrations in ppb. (Wilber and Hunter, 1975.)

Metal	Precipitation Concentration (ppb)	Stormwater Concentration (ppb)
Lead	45	900
Zinc	44	620
Copper	6.4	150
Nickel	3	80
Chromium	1.4	30

Table 59. METAL CONCENTRATIONS IN WET PRECIPITATION IN NORTHERN MINNESOTA Values are mean concentrations in ppb. (Eisinreich, 1981.)

Toxic Metal	Concentration (ppb)
Lead	8.0
Nickel	3.6
Copper	3.9
Zinc	147
Cadmium	0.73
Chromium	0.44

Table 60. CONCENTRATIONS OF ORGANICS AND METALS IN POTENTIAL URBAN RUNOFF SOURCE MATERIALS
These data are concentrations of "pure" materials, in mg/g (parts per thousand) for organics and in µg/g (parts per million) for metals. (Shaheen, 1975.)

Material	Grease (mg/g)	Petroleum (mg/g)	n-Paraffins (mg/g)	Lead (µg/g)	Chromium (µg/g)	Copper (µg/g)	Nickel (µg/g)	Zinc (µg/g)
Gasoline	1.3	1.3	1.3	663	15	4	10	10
Lubrication Grease	753.1	665.8	566.3	0	0	0	0	164
Motor Oil	989.2	937.7	850.0	9	0	3	17	1060
Transmission Fluid	985.6	941.7	875.4	8	0	0	21	244
Antifreeze	143.8	69.6	6.1	6	0	76	16	14
Undercoating	958.1	182.8	120.7	116	0	0	476	108
Asphalt Pavement	21.4	15.0	9.0	102	357	51	1170	164
Concrete	2.7	1.3	1.0	450	93	99	264	417
Rubber	191.6	97.8	56.0	1110	182	247	174	617
Diesel Fuel	385.3	307.8	209.7	12	15	8	8	12
Brake Linings	30.5	8.3	7.6	1050	2200	30600	7454	124
Brake Fluid	883.0	33.1	18.6	7	19	5	31	15
Cigarettes	30.0	21.2	2.7	492	71	716	193	560

C. TOXICANTS IN THE RECEIVING ENVIRONMENT

1. Interstitial Streamwater

(Tables and figures for this subsection begin on page 3-101.)

SUMMARY

- Interstitial streamwater samples (as collected by Metro) were rich in fine suspended particles and the analytical results were not representative of streamwater or its available constituents.
- Trace metals commonly found in both the urban and rural interstitial waters were arsenic, chromium, copper, zinc, cadmium, and lead.
- Benzene was the only organic priority pollutant found -- and only in the urban stream.
- The highest metal concentrations corresponded with wet season runoff.
- The high interstitial metal and organic concentrations were similar to concentrations in stormwater runoff.
- Virtually all of the detected lead was associated with the particulate matter (this is probably true of the other metals as well).
- Non-storm streamwater lead concentrations tended to be only 5 ppb but could rise as much as ten-fold during a storm.

(a) Metro's Results. Table 61 presents the Toxicant Inventory data on four samples of interstitial streamwater (one of which was a replicate) from Kelsey Creek, an urban stream, and two samples from Bear Creek, the semi-rural reference stream. Four trace metals were found in each of the six samples: arsenic, chromium, copper, and zinc; cadmium and lead were seen in five of the six samples. Of all the organic toxicants, only benzene appeared above detection limits and only in sample #16, Kelsey Creek, and its replicate.

Metal concentrations from the same site can be seen to vary greatly (as much as 200 times) depending upon whether the sample was taken during the dry or wet season (Table 62). Both Kelsey Creek and Bear Creek had much higher values during the high runoff periods. Although some of the metal concentrations were higher in Bear Creek, the limited number of interstitial samples makes comparison between streams unreliable. In addition, data from Richey (1982) showed higher total suspended solids (TSS) concentrations in the Bear Creek sample than in the Kelsey Creek sample taken at the same time, which could explain the observed differences in metal concentrations.

In fact, the high levels of fine suspended solids collected with the water in these samples raise substantial problems in data interpretation. The values observed are not representative of streamwater and reflect particle analyses rather than available toxicant levels. (See Richey's (1982) comments below.)

(b) Comparison With Runoff and Street Dust. The concentrations of priority pollutant metals found in Metro's rainy season interstitial water samples were generally greater than (but of the same magnitude as) those seen in stormwater runoff samples, as shown in Table 63. Although only one organic toxicant, benzene, was detected in interstitial sampling, it was found at the same concentrations as those seen in the urban runoff.

(c) Comparison With Other Local Data. Our interstitial streamwater sampling occurred in cooperation with the University of Washington's urban stream study, results of which are reported in Perkins *et al*. (1980), Sloane-Richey *et al*. (1981), Richey (1982), and Scott *et al*. (1982).

Richey's (1982) data for five metals in wet season interstitial water samples are presented in Table 64; differences between her results and Metro's may be at least partially explained by differences in analytical method: her data represent "exchangeable" or total recoverable metals, while Metro's results (Table 61) are total metals.

Analyses of total versus soluble lead levels by Richey showed that essentially all of the observed lead was associated with the particulate matter.

Streamwater samples tended to have lead concentrations only 1/100 to 1/10 as great as the interstitial samples. The mean lead concentration for Kelsey Creek streamwater during non-storm base flow periods was 5 (± 2) ppb. Streamwater lead concentrations during storm events rose to as high as 50 ppb (above EPA's acute criteria).

Much of the difference between wet and dry, stream and interstitial, may be explained by variation in total suspended solids. There were marked differences in TSS between the wet season and dry season interstitial samples and between the streamwater and interstitial water samples taken at the same time: 2.8 mg/l stream versus 53.9 mg/l interstitial for Bear Creek, and 7.6 mg/l stream versus 30.6 mg/l interstitial for Kelsey Creek (Richey, 1982). Lead in streamwater samples was found to correlate well with TSS concentrations, as shown in Figure 23. Richey (1982) observed, "Although the standpipe sampling technique provides a means for obtaining interstitial water in cobble-bottomed streams, it does not exclude silt particles. These particles, which are really a separate component from the water, make interpretation of chemical data difficult."

In a special study of Juanita Creek in 1976-1977, Brenner et al. (1978) found lead and chromium concentrations in the streamwater during storm events as high as 400 and 69 ug/l, respectively. In these storm periods, 18 of 41 lead samples and three of 41 chrome samples exceeded the 1976 "Red Book" (U.S. EPA, 1976) criteria of 50 ug/l. PCBs and pesticides were also tentatively identified during storm events, PCBs ranging from 0.06 to 5.21 ug/l and pesticides (major constituents: DDT and lindane) ranging from 0.001 to 0.302 ug/l in the streamwater samples.

(d) Natural Background Levels. Trace metals, unlike most of the organic priority pollutants, are found at low concentrations in all natural ecosystems and are basic components of the lithosphere (see Table 56).

Jenkins (1981) has attempted to estimate typical freshwater concentrations for some of the trace metals, as shown in Table 65. No mention is made as to whether these values are for total dissolved or ionic concentrations, nor the hardness of the typical water. Table 66 lists average concentrations of four trace metals in pristine freshwater lakes and reservoirs, along with their acute and chronic toxicity criteria.

It is worth noting that the acute toxicity concentrations for cadmium and copper are very close to the concentrations reported for pristine waters, and that chronic cadmium and lead toxicity criteria actually are exceeded.

Table 61. TOXICANTS IN INTERSTITIAL STREAMWATER
(Metro's Toxicant Inventory Data)

Samples are from Kelsey Creek, an urban stream, and Bear Creek, a semi-rural control stream. All values are concentrations in ppb= μg/l. Less than (<) values represent detection limits for undetected parameters; NCA = no criterion available; NA = not analyzed for.

ppb=μg/l	#16 Kelsey Creek 11/3/80 (wet season)	#17 Kelsey Creek Replicate of #16	#27 Bear Creek 8/7/81 (dry season)	#40 Kelsey Creek 8/20/81 (dry season)	#55A Kelsey Creek 3/12/82 (wet season)	#55B Bear Creek 3/16/82 (wet season)	W.Q. Criteria USEPA (1980a)	
							Freshwater Acute	Freshwater Chronic
Metals								
Antimony	<2	<2	<2	<3	<1	<1	NCA	NCA
Arsenic	40	40	4	3	24	46	440	NCA
Beryllium	0.5	0.5	< 0.1	< 0.3	0.3	0.5	NCA	NCA
Cadmium	1.2	1.5	0.2	< 0.1	0.7	3.6	0.6[a]	0.005[a]
Chromium (total)	41	39	1	4	45	78	NCA	NCA
Copper	68	63	2.4	5	100	230	5.0[a]	5.6
Lead	240	240	1	< 1	150	120	24[a]	0.09[a]
Mercury	<1	<1	< 0.4	< 1	< 0.5	< 0.5	4.1	0.20
Nickel	20	20	< 7	< 6	27	27	540[a]	28[a]
Selenium	< 2	< 2	< 3	< 2	< 2	< 2	260	35
Silver	13	0.6	< 0.2	< 0.2	< 0.5	< 0.5	0.3[a]	NCA
Thallium	< 1	< 1	< 0.5	< 1	< 1	< 1	NCA	NCA
Zinc	280	250	12	13	200	460	85[a]	47
Cyanides	<10	< 10	10	<10	NA	NA	52	3.5
Organics								
Benzene	22	24	< 1	< 1	< 1	< 1	NCA	NCA

[a] Criterion calculated using a water hardness value of 20 mg/l.

Table 62. SEASONAL DIFFERENCES IN INTERSTITIAL STREAMWATER METALS
(Metro's Toxicant Inventory Data)
All values are concentrations in ppb=μg/l.

Metal	Urban Stream			Rural Stream	
	winter (wet) season mean	(sd)[a]	summer (dry) season[b]	winter (wet) season[b]	summer (dry) season[b]
Arsenic	35	(±9)	3	46	4
Beryllium	0.4	(±.1)	< 0.3	0.5	< 0.1
Cadmium	1.1	(±.4)	< 0.1	3.6	0.2
Chromium	42	(±3)	4	78	1
Copper	77	(+20)	5	230	2.4
Lead	210	(±52)	< 1	120	1
Nickel	22	(±4)	< 6	27	< 7
Zinc	240	(±40)	13	460	12

[a] n=3 [b] n=1

Table 63. COMPARISON OF METALS IN RUNOFF AND INTERSTITIAL STREAMWATER
(Metro's Toxicant Inventory Data)
Values are average concentrations in ppb = μg/l.

Metal	Stormwater Runoff: Surrey Downs and Lake Hills (Kelsey Creek basin)			Interstitial Streamwater: Kelsey Creek winter (wet) season		
	Occurrence	mean	(sd)	Occurrence	mean	(sd)
Arsenic	21/21	13	(±12)	3/3	35	(±9)
Beryllium	0/21	--	--	3/3	0.4	(±.1)
Cadmium	21/21	0.7	(±.5)	3/3	1.1	(±.4)
Chromium	21/21	7	(±5)	3/3	42	(±3)
Copper	21/21	20	(±12)	3/3	77	(±20)
Lead	21/21	210	(±160)	3/3	210	(±52)
Nickel	12/21	12	(±4)	3/3	22	(±4)
Zinc	21/21	120	(±80)	3/3	240	(±40)

Table 64. METALS IN INTERSTITIAL STREAMWATER FROM VARIOUS SITES DURING THE WET SEASON

Samples are from sites on Kelsey and Bear Creeks; K5 and B1 are the sites used for Metro samples in Table 61. Values[a] are exchangeable (total recoverable) metal concentrations in ppb=μg/l. Samples were collected in February, 1980. (Richey, 1982.)

Site	Lead		Copper	Zinc		Chromium		Cadmium	
Kelsey Creek									
K2	280	(±54)	0[c]	136	(±15)	14	(±2)	1.5	(±1.1)
K4	211	(±25)	0	63	(± 8)	8	(±7)	1.8	(±0.9)
K4b	182	(±60)	0	38	(±27)	7	(±1)	1.2	(±0.8)
K5	179	(±56)	0	76	(±97)	10	(±5)	2.8	(±1.8)
K6	172	(±21)	0	29	(±17)	8	(±3)	1.4	(±1.3)
Kelsey mean	205	(±45)[b]	-	68	(±42)	9	(±3)[b]	1.8	(±0.6)
Bear Creek									
B1	107	(±57)	0	22	(±20)	3	(±1)	0.9	(±0.4)
B1b	76	(±42)	0	69	(±113)	4	(±2)	1.2	(±0.3)
B2	145	(±22)	0	33	(± 8)	4	(±3)	0.5	(±0.6)
Bear mean	109	(±35)[b]	-	41	(±25)	4	(±1)[b]	0.9	(±0.4)

[a] Data are given as the mean ± 1 standard deviation of the mean for three different standpipes. Whole stream averages are calculated as the mean of the different station means.

[b] Whole stream lead and chromium averages are significantly different at p = 0.05.

[c] No explanation was provided for non-detection of copper.

Table 65. BACKGROUND CONCENTRATIONS OF TRACE METALS IN FRESHWATER

These values--concentrations in ppb=ug/l--are a "global approximation" of background levels. (Jenkins, 1981.)

Element	ppb
Arsenic	0.4
Beryllium	1
Cadmium	80
Chromium	0.18
Copper	10
Lead	5
Mercury	0.08
Nickel	10
Selenium	20

Table 66. DISSOLVED TRACE METAL CONCENTRATIONS IN PRISTINE LAKES AND RESERVOIRS

Values are concentrations in parts per billion=ug/l.

	Background Levels		Freshwater Quality Criteria	
Metal	Seattle Watersheds[a]	Sierra Nevada Lakes[b]	Acute[c]	Chronic[d]
Cadmium	0.1	3	0.6	0.005
Copper	10	0.5-3	5	5.6
Lead	1	0.3-2	24	0.09
Zinc	5	0.7-5	85	47

[a] Personal Correspondence with City of Seattle Water Department Water Quality personnel, May, 1982.

[b] Average Background Levels of trace metals in 170 Sierra Nevada Pristine Soft-Water Lakes (Novotny and Chesters, 1981).

[c] Federal Acute Freshwater Quality Criteria (based upon a water hardness of 20 mg/l).

[d] Federal Chronic Freshwater Quality Criteria (based upon a water hardness of 20 mg/l).

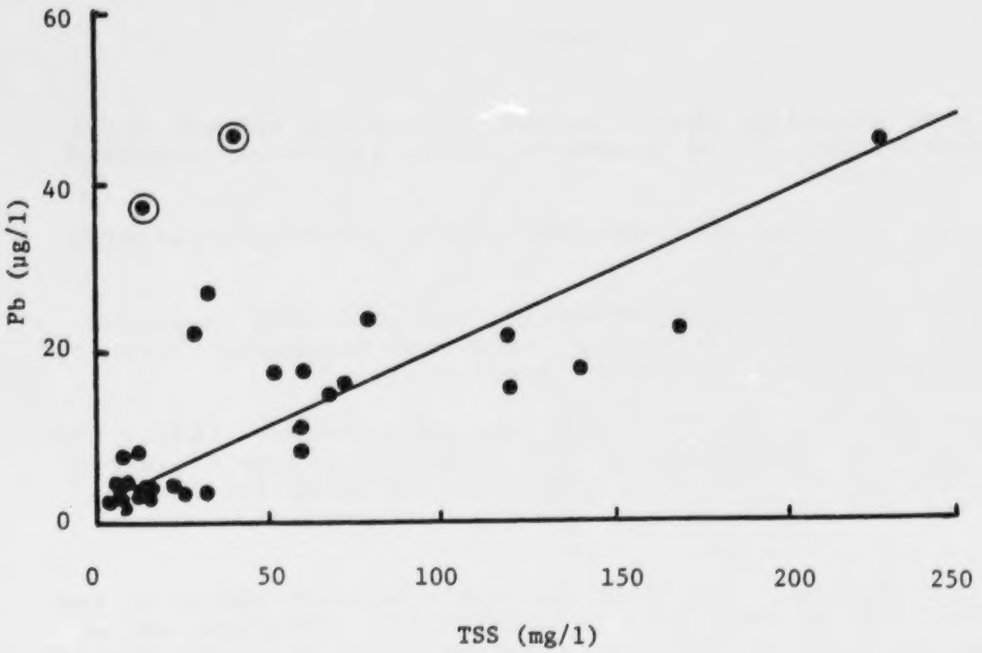


Figure 23.

CORRELATION BETWEEN TOTAL SUSPENDED SOLIDS AND EXCHANGEABLE LEAD IN STREAMWATER SAMPLES FROM KELSEY CREEK

Samples were collected between May, 1979, and June, 1981; $r=0.72$ with circled points excluded and $r^2=0.55$ with circled points included. (Richey, 1982.)

2. Stream Sediments

(Tables for this subsection begin on page 3-109.)

SUMMARY

- The most urbanized stream tended to have the highest metal concentrations in the sediments, while the least urbanized had the lowest.
- Very few organics were detected and no occurrence patterns could be determined.
- Arsenic, lead, cadmium, chromium, and zinc tend to exceed natural background levels in the stream sediments; arsenic consistently, and the others occasionally.
- It appears that dilution with natural streambank (soil) sediments drops contributions from runoff particles to levels near or, in the case of organics, below detection limits.

(a) Metro's Results. Streambed sediments were collected by two distinct methods, as described in Section II. The first set of samples was obtained by using an aluminum scoop to remove the top three to four inches of bottom material from sites in three urban streams (Kelsey, Juanita and Thornton Creeks) and one semi-rural stream (Bear Creek); the Kelsey and Bear sites were the same as those used for interstitial water sampling. The second set of samples employed a freeze-coring technique to more thoroughly collect all particles in the area sampled. Sites were the same as above in Thornton and Bear Creeks; a different location was chosen in Kelsey to represent a fine sediment deposition area (see Figure 7 in Section II).

Tables 67 and 68 present the metals data for the 17 samples collected. From the samples collected at the same locations, no significant differences were found between the data sets of the two sampling techniques. All the metals (except arsenic), on the other hand, showed significant differences between the two different Kelsey Creek sites. Table 69 presents summary statistics for the four streams. As these data show, Thornton Creek, the most urbanized of the streams sampled, tended to have the highest metal concentrations in comparable sediment samples, while Bear Creek, the least urbanized, consistently had the lowest concentrations. The fine sediment site in Kelsey Creek had concentrations equivalent to (i.e., not statistically different from) the Thornton Creek sediments.

Very few organic compounds were detected in the stream sediments. Table 70 presents the data for the six samples in which any organics were seen. Because detection was so scattered, no inferences should be made regarding differences between streams for the organics.

(b) Comparison With Other Metro Data. A comparison of stream sediment concentrations (Tables 68 and 69) with those of street dust (Tables 31 and 41) yields some interesting points. For the metals originating with motor vehicles and their fuels and lubricants (lead, zinc, copper, cadmium, and chromium), the concentrations in street dust are generally ten to 100 times higher than in stream sediments. (It should be noted in such a comparison, however, that Metro's stream sediment values are wet weight which could make them one-half to one-third the comparable dry weight values -- conversions have been included in Table 69). The remaining inorganics were seen in similar concentrations in both matrices. While the volatile organic and phenolic compounds tend to appear sporadically and in comparable concentrations in dust and sediment, the heavier, more particulate-associated extractable organics (e.g., PAHs) tend to follow the pattern observed with the auto-related metals; i.e., concentrations in street dust are ten to 100 times the concentrations seen in stream sediments. It appears that dilution with natural streambank (soil) sediments drops most of the street dust-associated organics below detection limits when they are mixed into the stream sediments.

(c) Comparison With the Literature. The only available data on toxicants in urban stream sediments were those of the Field/Turkeltaub analyses (Ammon, 1980, in Rolan et al., N.D.). Streambed sediments at stormdrain outfall sites from three areas (California, Texas and New Jersey) were analyzed for priority pollutants. These data are presented in Table 71.

Values for the metals tend to fluctuate, some significantly higher and some significantly lower than the Metro results. Arsenic and chromium, for example, are generally five to ten times higher in Metro samples (see Tables 31 and 69). The organic compounds tend to be at the same concentrations Metro found in street dust (see Table 41). Results close to the street dust concentrations are to be expected in the Ammon data, since the samples were collected immediately adjacent to stormdrain outfalls in the urban streams.

(d) Natural Background Levels. As has been pointed out earlier, it is important to remember that the trace metals occur naturally as elements in soils and the earth's crust. They become pollutants only when their available concentrations in a given water body exceed the assimilative capacities or toxic thresholds of the biological communities found there.

Table 56 presented general "background" concentrations of ten metals from various references. A comparison of these concentrations with the concentrations seen in urban streams reveals that only arsenic and occasionally lead, cadmium and chromium exceed background concentrations and that beryllium, copper, nickel and zinc in our stream sediments tend to be close to or lower than most of the average background figures.

Table 67. METALS IN STREAM SEDIMENTS -- FROM SAMPLES COLLECTED BY ALUMINUM SCOOP

(Metro Toxicant Inventory Data)

Values are concentrations in mg/kg=ppm, wet weight. Less than (<) values represent detection limits.

mg/kg=ppm	#24 - Kelsey Creek 8/6/81	#25 - Kelsey Creek (Replicate of #24)	#26 - Kelsey Creek 8/6/81	#28 - Bear Creek 8/7/81	#29 - Bear Creek 8/7/81	#36 - Juanita Creek 8/13/81	#35 - Juanita Creek 8/13/81	#38 - Thornton Creek 8/13/81	#37-Thornton Creek 8/13/81
Antimony	< 0.2	< 0.2	< 0.4	< 0.2	1.3	< 0.2	< 0.2	< 0.2	< 0.2
Arsenic	6.0	8.0	18	5.0	11	11	16	7.0	12
Beryllium	0.11	0.12	0.13	0.08	0.10	0.15	0.17	0.13	0.14
Cadmium	0.07	0.08	0.12	0.08	0.05	0.07	0.10	0.11	0.16
Chromium	68	52	45	24	23	44	58	40	46
Copper	4.7	4.9	5.6	1.8	2.8	6.6	6.5	5.9	8.7
Lead	2.0	2.9	4.1	1.0	< 1	2.0	6	15	29
Mercury	< 0.05	< 0.05	0.12	< 0.05	0.14	< 0.05	< 0.05	< 0.05	< 0.05
Nickel	9.0	9.0	13	1.8	5.2	20	19	12	19
Zinc	29	29	39	20	30	28	37	42	55
Cyanides	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.7	< 0.2	< 0.2

Table 68. METALS IN STREAM SEDIMENTS -- FROM SAMPLES COLLECTED BY FREEZE-CORER (Metro Toxicant Inventory Data)

Values are concentrations in mg/kg=ppm, wet weight. Less than (<) values represent detection limits.

mg/kg=ppm	#52 Thornton Creek 3/2/82	#53 Bear Creek 3/2/82	#54 Kelsey Creek 3/2/82	#69 Bear Creek 5/20/82	#74 Kelsey Creek 5/20/82	#76 Thornton Creek 6/4/82	#78 Bear Creek 6/4/82	#80 Kelsey Creek 6/4/82
Antimony	<0.5	<0.5	< 0.5	0.11	<0.5	< 0.6	< 0.6	<0.6
Arsenic	15	5.4	15	8.3	12	15	8.8	14
Beryllium	0.19	0.07	0.18	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
Cadmium	0.31	0.06	0.26	< 0.4	< 0.4	< 0.3	< 0.3	<0.3
Chromium	40	14	41	11	17	23	11	19
Copper	10	1.6	11	3.6	10	12	7	10
Lead	37	1.6	20	2.2	23	18	3.4	6.4
Mercury	0.01	<0.01	0.01	< 0.03	< 0.03	< 0.05	< 0.05	<0.05
Nickel	27	4.5	15	8.2	14	22	7.9	17
Zinc	57	17	58	24	46	56	25	39
Cyanides	<0.05	<0.05	0.09	< 0.1	< 0.1	< 0.1	< 0.1	<0.1

Table 69. SUMMARY OF METALS IN STREAM SEDIMENTS.
(Metro Toxicant Inventory Data)
All values are mean concentrations in mg/kg=ppm from data in Table . Level of urbanization is approximately Thornton >Juanita≥ Kelsey≥ Bear.

	Kelsey							
	medium coarse (n=3)				fine (n=3)			
	wet weight		dry weight[a]		wet weight		dry weight[a]	
ppm=mg/kg	mean	(+sd)	mean	(+sd)	mean	(+sd)	mean	(+sd)
Arsenic	11	(±6)	33	(±18)	14	(±2)	42	(+6)
Beryllium	0.12	(±.01)	0.36	(±.03)	0.18 (n=1)	(-)	0.54	(-)
Cadmium	0.09	(±.03)	0.3	(±.1)	0.26 (n=1)	(-)	0.78	(-)
Chromium	55	(±12)	165	(±36)	26	(±13)	78	(± 39)
Copper	5	(±0.5)	15	(±1.5)	10	(±0.6)	30	(± 2)
Lead	3	(±1)	9	(±3)	16	(±9)	48	(± 27)
Nickel	10	(±2)	30	(±6)	15	(±2)	45	(± 6)
Zinc	32	(±6)	96	(±18)	48	(±10)	144	(± 30)

	Thornton				Juanita				Bear			
	medium coarse (n=3)				medium coarse (n=2)				medium coarse (n=5)			
	wet weight		dry weight[a]		wet weight		dry weight[a]		wet weight		dry weight[a]	
ppm=mg/kg	mean	(+sd)	mean	(+sd)	mean	(+sd)	mean	(+sd)	mean	(+sd)	mean	(+sd)
Arsenic	12	(±4)	36	(±12)	14	(±4)	42	(+12)	8	(±3)	24	(±9)
Beryllium	0.11	(±.04)[b]	0.33	(±.12)	0.16	(±.01)	0.48	(+.03)	0.05	(±.02)[b]	0.15	(±.06)
Cadmium	0.14	(±.07)	0.42	(±.21)	0.08	(±.02)	0.24	(+.06)	0.04	(±.01)[b]	0.12	(±.03)
Chromium	37	(±10)	111	(±30)	51	(+10)	153	(+30)	17	(±6)	51	(±18)
Copper	9	(±3)	27	(±9)	7	(±0.1)	21	(+.3)	3	(±2)	9	(±6)
Lead	25	(±10)	75	(±30)	4	(±3)	12	(+9)	2	(±1)[b]	6	(±3)
Nickel	20	(±6)	60	(±18)	20	(±1)	60	(+3)	6	(±3)	18	(±9)
Zinc	52	(±7)	156	(±21)	32	(±6)	96	(+18)	23	(±5)	69	(±15)

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[a] Conversion to dry weight is based on a rough factor of 3 different wet/dry, from unpublished Metro data.

[b] Estimates of mean and (sd) are for those metals not found 100% of the time are based on Atichison's delta distribution (see Appendix B).

Table 70. ORGANICS IN STREAM SEDIMENTS
(Metro's Toxicant Inventory Data)

Only the samples in which one or more organic compounds were detected are presented; all samples listed in Tables 67 & 68 were analyzed. Values are concentrations in µg/kg=ppb. Dashes (--) indicate none detected.

µg/kg=ppb	OCCURRENCE	Aluminum Scoop Sampling				Freeze-core sampling	
		#24-Kelsey Creek 8/6/81	#28-Bear Creek 8/7/81	#35-Juanita Creek 8/13/81	#37-Thornton Creek 8/13/81	#54-Kelsey Creek 3/2/82	#69-Bear Creek 5/20/82
ALIPHATICS							
Trichloromethane	1/17	--	--	35	--	--	--
MONO-AROMATICS							
Benzene	1/17	--	--	210	--	--	--
Ethylbenzene	1/17	--	--	21	--	--	--
Toluene	1/17	--	--	22	--	--	--
PHENOLICS							
4-nitrophenol	1/17	--	--	--	--	--	100
Pentachlorophenol	1/17	--	--	--	--	--	60
2,4 dimethylphenol	1/17	--	--	--	--	77	--
PHTHALATES							
Bis(2) ethylhexyl	1/17	39	--	--	--	--	--
Butyl benzyl	2/17	320	720	--	--	--	--
Di-n-octyl	1/17	--	--	--	2000	--	--
PAHs							
Phenanthrene	2/17	26	--	--	--	50	--
Pyrene	2/17	28	--	--	--	83	--
Fluoranthene	2/17	30	--	--	--	72	--
Benzo(a)pyrene	1/17	--	--	--	--	38	--
Benzo(k)fluoranthene	1/17	--	--	--	--	79	--
Chrysene	1/17	--	--	--	--	72	--

Table 71. METAL AND ORGANIC PRIORITY POLLUTANTS IN URBAN STREAM SEDIMENTS FROM THREE U.S. LOCATIONS

Samples were collected immediately off storm drain outfalls. Values are concentrations in µg/kg=ppb for the organic compounds and mg/kg(ppm) for the metals.[a] Preliminary data from Ammon (1980). (See Table 24 for comparable stormwater runoff results.)

Priority Pollutant	Concentration in sediment, range (µg/kg)	Sites reporting[b]
ORGANICS		
Monocyclic Aromatic Hydrocarbons		
Benzene	--	--
Ethylbenzene	12	13
Toluene	20-100	13,14
Polycyclic Aromatic Hydrocarbons		
Benzo(a)anthracene (1,2-Benzanthacene)	1,100-2,400	13,14
Benzo(b)fluoranthene (3,4-Benzofluoranthene)	1,200-1,400	13,14
Benzo(k)fluoranthene (11,12-Benzofluoranthene)	1,200-1,400	13,14
Benzo(a)pyrene	600-1,200	13,14
Indeno (1,2,3-cd)pyrene	260	13
Benzo(ghi)perylene (1,12-Benzoperylene)	560	13
Acenaphthene	110	13
Acenaphthylene	--	
Anthracene	375-1,100	12,13,14
Chrysene	1,500-2,400	13,14
Fluoranthene	1,200-2,300	12,13,14
Fluorene	87-210	13,14
Naphthalene	47	13
Phenanthrene	375-2,000	12,13,14
Pyrene	1,200-2,600	12,13,14
Dibenzo(a,h)anthracene (1,2:5,6-Dibenzanthracene)	--	--
Halogenated Aliphatic Hydrocarbons		
Chloromethane (Methyl chloride)	0.20	13
Dichloromethane (Methylene chloride)	1.3-1.7	13,14
Trichloromethane (chloroform)	--	--
1,2-Dichloropropane	--	--

Table 71 (Continued). METAL AND ORGANIC PRIORITY POLLUTANTS IN URBAN STREAM SEDIMENTS FROM THREE U.S. LOCATIONS

Priority Pollutant	Concentration in sediment, range (µg/kg)	Sites reporting[b]
Bromodichloromethane (Dichlorobromomethane)	--	--
Trichlorofluoromethane	--	--
1,1,1-Trichloroethane	--	--
Hexachloroethane	5,600	13
Phthalates		
Diethyl phthalate	--	--
Di-n-butyl phthalate	370-2,500	12,13,14
Bis(2-ethylhexyl)phthalate	130-59,000	12,13,14
N-Butyl Benzyl phthalate (Butylbenzyl phthalate)	1,200	12
Monocyclic Aromatic Hydrocarbons (Phenols)		
Phenol	32	13
Pentachlorophenol	--	--
2,4-Dimethyl phenol	--	--
2,4,6-Trichlorophenol	--	--
Nitrosamines and Other N Compounds		
Diphenyl Nitrosamine (N-Nitro sodiphenylamine)	--	--
Pesticides		
4,4'-DDE	180	13

Table 71 (Continued). METAL AND ORGANIC PRIORITY POLLUTANTS IN URBAN STREAM SEDIMENTS FROM THREE U.S. LOCATIONS

Priority Pollutant	Concentration in sediment, range (mg/kg)[a]	Sites reporting[b]
METALS AND OTHER INORGANICS:		
Antimony	<3.00-16	13,14
Arsenic	2.30-2.80	13,14
Beryllium	<0.20	13,14
Cadmium	≈0.80-≈1.0	13,14
Chromium	8.10-14.0	13,14
Copper	7.0-17.0	13,14
Lead	24.0-1300	13,14
Mercury	0.26-2.39	13,14
Nickel	≈3.0-5.90	13,14
Selenium	1.40-2.80	13,14
Silver	<0.50	13,14
Thallium	<0.20	13,14
Zinc	37.0-160.0	13,14

[a] Values for metals were listed as µg/kg(=ppb) in Rolan et al. (N.D.), from which these Ammon (1980) data were taken, but we assume that this label was a typo and that the levels are in fact mg/kg(=ppm).

[b] Key to sites:

12: Bottom sediment from Coyote Creek at storm drain outfall, San Jose, CA.
13: Sediment from storm sewer outfall, Austin, TX.
14: Sediment from Shabakunk Creek, beneath outfall of Lawrence Shopping Center storm sewer, near Trenton, N.J.

3. Lake Sediments

(Tables and figures for this subsection begin on page 3-120.)

SUMMARY

- Only small differences existed in toxicant concentrations between the various lake sediment samples.
- No single site in Lake Washington had consistently higher or lower toxicant concentrations.
- Very few organic compounds were detected in the lake sediments in the Toxicant Inventory analyses, but numerous organics have been found to date in Metro's TPPS samples of lake sediments.
- Lake sediment metal and PAH concentrations tend to be similar to those detected in streambed samples; further dilution of stream and stormdrain inputs does not appear to significantly lower toxicant levels.
- Arsenic, copper, lead, mercury and zinc concentrations in lake sediments tend to be elevated over background levels.

(a) Metro's Results. Twelve sediment samples were collected from Lake Washington for priority pollutant analysis: nine from embayments (five of which have direct urban stream inputs), one below a Mercer Island storm drain, one nearshore -- away from any direct inputs (our control), and one from the deep, central part of the lake.

The results are presented in Tables 72 and 73 for trace metals and organics, respectively. Only small differences existed in trace metal concentrations between the various sites. The greatest variation was shown by chromium, lead, nickel, and silver, which had approximately a ten-fold difference between minimum and maximum values. No one site contained a predominance of the highest sample values. Some with the highest value of one metal had the lowest of another (e.g., Union Bay with high lead, low chromium). Juanita Creek mouth tended to have high concentrations overall, yet a little farther offshore (Juanita Bay mouth) the concentrations were among the lowest encountered. This variability without obvious pattern resulted in our pooling data and developing average lake sediment metal concentrations, as shown in Table 72.

Few organic compounds were detected in any of the samples and no intersite comparisons are possible.

(b) Comparison With Metro's Stream Sediment Data. Trace metal concentrations in the Lake Washington sediment samples were very similar to those in the streambed sediments. While lead and copper concentrations were slightly higher in the lake, arsenic, beryllium and chromium were slightly lower and no differences were noticeable for cadmium, nickel and zinc. Considering the overall variability of the data, no general trends are evident.

Comparison of organic data for lake and stream sediments is difficult due to the few observations above the detection limits. Those organic compounds observed in both sets of samples (e.g., the PAHs) tend to be at comparable concentrations.

(c) Comparison With the Literature. A survey of other studies reporting concentrations of the trace metals in Lake Washington sediments began with an examination of Metro's Toxicant Pretreatment Planning Study (TPPS) data (unpublished). Table 74 presents mean concentrations collected in 1981 from five sites representing both nearshore and deep-lake deposition. Except for chromium, the TPPS concentrations are five to ten times higher than samples analyzed in this study (see Table 72); these differences are probably accounted for in the different units reported: while the TPPS data are ppm dry weight, the Toxicant Inventory data are ppm wet weight. A review of the TPPS data for total solids (not determined in the Toxicant Inventory samples) reveals that solids account for 30 to 50% of the total wet weight sample; thus, a wet weight value may be two to three times lower than the equivalent dry weight (conversion ratios supported by Tomlinson *et al*. (1980) data).

A study of copper, lead, and zinc sediment levels in Lake Washington by Spyridakis and Barnes (1976 and 1978) found concentrations similar to those in Metro's TPPS study and comparable to converted Toxicant Inventory concentrations. Table 75 gives values for both nearshore and deep-lake samples.

The study of combined sewer overflows and storm drains in Lake Washington by Tomlinson *et al*. (1980) also included analyses of copper, lead and zinc in sediments, as shown in Table 76. They found that the fine particles in storm drain discharges, which carried the greatest concentrations of metals, tended not to settle immediately off the outfalls but rather to contribute to the general sediment burden in the lake.

Crecelius (1975) reported concentrations of arsenic in Lake Washington surface sediments ranging from 15 to 210 ppm dry weight, with a mean of 81 (± 51); analyses were by neutron activation. These figures are also comparable to the TPPS results.

Contrasting metal values in Lake Washington sediments with those of other lakes can only be done in general terms due to differences in composition and particle size. Table 77 presents average background concentrations and maximum values in sediment core samples for trace metals from four U.S. lakes, including Lake Washington. While it is difficult to draw inferences from these summarized data, the high maxima reported in Lake Washington are notable.

Priority pollutant organics have been analyzed for in Lake Washington sediments as part of Metro's TPPS project. Preliminary (unpublished) concentration values for those compounds observed in our samples are presented in Table 78. Pesticide and solvent concentrations were similar in both data sets, but PAH concentrations tended to be an order of magnitude greater in the TPPS samples, an unaccounted-for result. The TPPS project also detected a greater variety of organic priority pollutants. A summary of all of the types of compounds found, along with their concentration ranges, is reported in Table 79. Also in this table is a list of compounds and concentration ranges from an earlier unpublished study (1979) done for Metro as a preliminary examination of sediment concentrations below storm drains and combined sewer overflows in Lake Washington.

Wakeham (1976) and Wakeham and Carpenter (1976) reported concentrations of total aliphatic hydrocarbons in the surface sediments (0 - 2 cm) of Lake Washington ranging from 280 to 1,700 ppm, with a mean of 1,400 ppm. Concentrations were reported to be slightly less in the Sammamish and Cedar River deltas due to dilution by natural erosion material. Background concentrations of total aliphatics in deep sediments deposited before 1880 ranged from ten to 160 ppm, with a mean of 32 ppm. The increase in aliphatics in the last 100 years was credited to use of petroleum products. Wakeham (1976 and 1977) determined that rivers and storm drains contribute about equal loads of hydrocarbons to the lake (85% combined), while rainfall and dustfall contribute only minor amounts.

Wakeham *et al*. (1980a and b) examined Lake Washington sediments for polycyclic aromatic hydrocarbons (PAHs) by GC/MS. Samples from the surface sediments (0 - 3 cm) had a mean total PAH concentration of approximately seven ppm, out of a total aromatic fraction of 50 ppm. Background concentrations in deep sediments were about one ppm total PAHs out of five to ten ppm total aromatics. Figure 24 presents their PAH profiles in three sediment levels. The wide variety found in the surface layer matches the street dust profile (see Figure 22) almost exactly.

(d) Natural Background Concentrations. In their summary of chemical contaminants in Puget Sound for NOAA, Dexter *et al*. (1981) reported concentrations of trace metals in bottom sediments originating from natural erosion, as presented in Table 80.

Spyridakis and Barnes (1976) give Lake Washington sediment sample concentrations for copper, zinc, and lead deposited prior to 1900. Table 81 shows these figures. Crecelius (1975) reported the background concentration of arsenic in Lake Washington sediments as ten ppm. A comparison between Metro's lake sediment samples and the reported background values reveals that chromium, copper, lead, nickel and zinc concentrations are elevated to varying degrees.

For organic toxicants, Wakeham et al. (1980a and b) provided data on natural concentrations of PAHs (pre-1880) in Lake Washington sediment cores. These were found to have a concentration of approximately one part per million total PAHs, which were almost entirely phenanthrene and perylene of natural origin (see Figure 24). Blumer et al. (1977) report that total PAH concentrations of around 5 ppm in soils and sediments "may well represent a [current] worldwide PAH background." Wakeham and Carpenter found concentrations of total aliphatic hydrocarbons in pre-industrial sediments of Lake Washington (>30 cm core depth) at an average concentration of 32 ppm.

Table 72. METALS IN LAKE WASHINGTON SEDIMENTS
(Metro's Toxicant Inventory Data)

Capital letters after the sample descriptors indicate the location of the samples on the map on Figure 8 (p. 2-20). All values are concentrations in mg/kg=ppm, wet weight.[a]

mg/kg=ppm	#44-Lyons Creek Mouth-A 11/5/81	#45-Juanita Creek Mouth-B 11/5/81	#46-Andrews Bay-C 11/5/81	#47-Union Bay-D 11/20/81	#48-Fairweather Bay-E 11/20/81	#49-Fairweather Bay-E 11/20/81	#50-Yarrow Bay-F 11/20/81	#64-Control Station #2-G 4/26/82	#65-Off Storm Drain #20-H 4/26/82	#66-Juanita Bay Mouth-I 4/26/82	#67-Mid-Lake Station 0550-J 4/26/82	#68-Mercer Slough Mouth-K 4/26/82	Mean[a]	(± Standard Deviation)
Arsenic	5.9	11	6.5	3.6	6.1	6.8	8.5	6.3	9.1	4.8	11	7.9	7.3	(±2.3)
Beryllium	0.07	0.08	0.07	0.03	0.02	0.03	0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.1	0.03	(±.01)[b]
Cadmium	0.1	0.2	0.2	0.24	0.15	0.12	0.12	< 0.5	< 0.5	< 0.5	< 0.5	< 0.4	0.09	(±.03)[b]
Chromium	28	50	15	5.7	9.6	9.6	13	18	25	18	11	8.8	17.6	(±12.2)
Copper	5.0	8.1	4.9	11	11	12	10	7.3	13	3.0	13	12	9.2	(±3.5)
Lead	20	29	18	88	30	30	56	16	15	8.0	35	30	31.2	(±21.7)
Mercury	0.05	0.05	0.05	0.05	0.04	0.03	0.03	0.04	0.055	0.035	0.08	0.05	0.05	(±.01)
Nickel	15	19	3.3	4.4	9.1	9.6	12	17	23	13	10	8.6	11.9	(±5.7)
Silver	< 0.04	0.23	0.07	0.12	< 0.04	< 0.04	< 0.04	< 0.2	0.4	< 0.2	0.3	< 0.2	0.09	(±.05)[b]
Zinc	29	38	22	45	31	32	47	20	26	18	26	39	31.1	(±9.5)
Cyanides	< 0.1	< 0.1	< 0.1	< 0.05	< 0.05	< 0.05	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.1	--	--

[a] Conversion of means from wet weight to dry weight is shown in Table 74 .

[b] Means for elements found less than 100% of the time are estimated using Aitchison's delta distribution (see Appendix B).

Table 73. ORGANIC TOXICANTS IN LAKE WASHINGTON SEDIMENTS
(Metro's Toxicant Inventory Data)

Capital letters after the sample descriptors indicate the location of the samples on the map in Figure 8 . All values are concentrations in μg/kg=ppb.

μg/kg=ppb	#44-Lyons Creek Mouth-A 11/5/81	#45-Juanita Creek Mouth-B 11/5/81	#46-Andrews Bay-C 11/5/81	#47-Union Bay-D 11/20/81	#48-Fairweather Bay-E 11/20/81	#49-Fairweather Bay-E 11/20/81	#50-Yarrow Bay-F 11/20/81	#64-Control Station #2-G 4/26/82	#65-Off Storm Drain #20-H 4/26/82	#66-Juanita Bay Mouth-I 4/26/82	#67-Mid-Lake Station 0550-J 4/26/82	#68-Mercer Slough Mouth-K 4/26/82
PESTICIDES:												
Dieldrin									0.50			
4,4-DDE								2.6	2.2			
4,4-DDD								4.6				5
β-endosulfan												5
γ-BHC								0.42				
HALOGENATED ALIPHATICS:												
1,1,-trichloroethane			71									
Methylene chloride[a]			550[a]									
MONOCYCLIC AROMATICS:												
Toluene	300											7
PHTHALATE ESTERS:												
Butylbenzyl phthalate[b]				500[b]			160[b]					
PAHs:												
Fluoranthene				72								
Benzo(a)pyrene				61								
3,4-benzofluoranthene							54					
Benzo(k)fluoranthene							54					
Pyrene		54		83			51					

[a] Laboratory contamination likely.

[b] Method blank for samples #47-50 showed some butylbenzyl phthalate contamination.

Table 74. 1981 METRO T.P.P.S. DATA ON METALS IN LAKE WASHINGTON SEDIMENTS

These data are preliminary, unpublished results. Values are concentrations in mg/kg = ppm, dry weight.

	Lake Washington sites					TPPS		Toxicant Inventory Lake Washington data (converted to dry weight)[f]	
mg/kg=ppm	(a)	(b)	(c)	(d)	(e)	mean	(±sd)	mean	(±sd)
Arsenic	330	58	120	190	49	150	(±120)	22	(±7)
Beryllium	0.11	0.07	0.34	0.17	0.45	0.23	(±.16)	0.09	(±.03)
Cadmium	0.86	1.2	2.6	1.7	0.91	1.5	(±.7)	0.3	(±.09)
Chromium	34	31	48	32	31	35	(±7)	53	(±37)
Copper	35	35	70	47	45	46	(±14)	28	(±10)
Lead	70	212	150	180	210	160	(±60)	94	(±65)
Mercury	0.065	0.16	0.35	0.34	3.1	0.8	(±1.3)	0.15	(±.03)
Nickel	50	45	60	46	37	48	(±8)	36	(±17)
Silver	0.98	1.2	3.1	2.1	1.6	1.8	(±.8)	0.3	(±.15)
Zinc	98	150	197	150	135	150	(±35)	93	(±28)
Cyanides	3.1	1.3	3.1	2.1	11	4.1	(±3.9)	--	--

Locations:

- (a) Sammamish River Delta.
- (b) Thornton Creek Delta.
- (c) Central Basin.
- (d) Mercer Island Floating Bridge.
- (e) Portage Bay.

[f] Conversion of wet weight to dry weight using factor of 3.

Table 75. CONCENTRATIONS OF COPPER, LEAD, AND ZINC IN LAKE WASHINGTON BOTTOM SEDIMENTS

Values are mean (and range) concentrations in mg/kg=ppm dry weight (Spyridakis and Barnes, 1976.)

	Lake Washington sample types			
mg/kg=ppm	25 Meter Depth[a]		Deep Basins[b]	
copper	39	(22-47)	46	(30-78)
lead	131	(102-155)	192	(150-294)
zinc	135	(110-158)	192	(170-223)

[a] Depth of sediment layer = 0-2 cm
[b] Depth of sediment layer = 0-1 cm

Table 76. CONCENTRATIONS OF THREE METALS IN NEARSHORE LAKE WASHINGTON SEDIMENTS IMMEDIATELY OFF A STORM DRAIN AND IN A CONTROL AREA

Values are concentrations in mg/kg=ppm dry weight. (Tomlinson et al., 1980.)

	storm drain				control site			
	0-0.5 cm		7-8 cm		0-0.5 cm		7-8 cm	
	mean	(±sd)	mean	(±sd)	mean	(±sd)	mean	(±sd)
copper	47	(±26)	42	(±24)	20	(±10)	7	(±3)
lead	89	(±53)	46	(±33)	87	(±47)	21	(±6)
zinc	61	(±27)	35	(±26)	131	(±32)	51	(±24)

Table 77. TRACE METALS IN SEDIMENTS FROM FOUR U.S. LAKES.

Values are average background and maximum concentrations in ppm=mg/kg, from a number of sources as cited in Forstner and Wittman (1981).

	Lake Michigan[b]		Wisconsin Lakes[b]		Lake Washington[a]		Lake Erie[b]	
ppm=mg/kg	background	max.	background	max.	background	max.	background	max.
Arsenic	11	22	2	51	10	200	0.6	3.2
Cadmium	ND	ND	2.5	4.6	ND	ND	0.14	2.4
Chromium	77	85	7	49	ND	ND	13	42
Copper	44	75	22	268	16	50	18	59
Lead	40	145	14	124	20	400	ND	ND
Mercury	0.04	0.2	0.24	1.12	0.1	1.0	0.004	4.48
Nickel	54	44	34	50	ND	ND	40	95
Zinc	120	317	15	92	60	230	7	42

[a] Lake Washington data were compiled from Barnes and Schell (1973), Crecelius and Piper (1973), Schell (1974), and Crecelius (1975).

[b] Other data were compiled from numerous sources cited in Forstner and Wittmann (1981).

Table 78. 1981 METRO T.P.P.S. DATA ON ORGANIC TOXICANTS IN LAKE WASHINGTON SEDIMENTS

Concentrations from the preliminary results of the TPPS project for those organic compounds that were found in the Toxicant Inventory samples (see Table 73) are presented for four Lake Washington sites. Values are concentrations in µg/kg=ppb.

	Lake Washington sites			
µg/kg=ppb	(a)	(b)	(c)	(d)
PESTICIDES:				
Dieldrin	0.5	--	--	--
4,4-DDE	2.2	--	--	--
4,4-DDD	2.2	3.2	0.45	0.85
HALOGENATED ALIPHATICS:				
methylene chloride*	--	740	550	1600
MONOCYCLIC AROMATICS:				
Toluene	--	--	18	--
PHTHALATE ESTERS:				
Butyl benzyl phthalate	360	92	--	100
PAHs:				
Fluoranthene	500	250	1400	190
Benzo(a)pyrene	--	200	--	--
Benzo(b)fluoranthene	--	200	240	190
Benzo(k)fluoranthene	--	165	280	185
Pyrene	--	345	1500	145

Locations:

(a) Sammamish River Delta.
(b) Thornton Creek Delta.
(c) Central Basin.
(d) Mercer Island Floating Bridge.

*Laboratory contamination likely.

Table 79. CONCENTRATION RANGES FOR ORGANIC TOXICANTS IN LAKE WASHINGTON SEDIMENTS FROM T.P.P.S. AND PREVIOUS METRO STUDY

Preliminary results from the TPPS and unpublished data from an earlier study are presented as concentration ranges in µg/kg=ppb.

µg/kg=ppb	TPPS (n =26)	Preliminary Study (n = 26)
PESTICIDES:		
DDT	2	3200
DDD	0.6 — 29	320
DDE	0.35 — 5	78
Dieldrin	0.5	
ALL PCB's:	0.3 — 570	ND or N/A*
Halogenated Aliphatics:		
All Methanes	< 1 — 5000	0.1-508
All Ethanes	3 — 13	0.9-19
All Ethenes or Ethylenes	2 — 6	ND
All Propanes	3	ND
All Ethers:	1000	0.4-150
Monocyclic Aromatics:		
All Benzenes	< 1 — 500	0.9-60
All Toluenes	< 2 — 30	1.4-7.2
Phthalate Esters:		
Bis(2-ethylhexyl)	ND	120-32,000
Butylbenzyl	< 50 — 360	11-230
Di-n-butyl	< 6 — < 150	30-130
Di-n-octyl	150 — 9100	140-1200
Di-ethyl	ND	6.1-62
Di-methyl	< 5 — 41	2.2-9
Nitrosamines:	ND	5.1-67
Polycyclic Aromatics:		
Acenaphthene	< 70 — 380	2.3-290
Acenaphthylene	< 4	1.6-11
Anthracene	60 — 1000	20 -500
Benzo(a)Anthracene	< 12 — 200	1.6-540
Benzo(b)Fluoranthene	150 — 930	8.4-310
Benzo(k)Fluoranthene	130 — 1100	20 -320
Benzo(a)Pyrene	< 40 — 1000	8.1-91
Chrysene	< 10 — 430	15 -330
Fluoranthene	< 10 — 3800	19-1300
Fluorene	< 70 — 240	3.6-470
Indeno (1,2,3-c,d)Pyrene	210 — 520	4.9-73
Naphthalene	980 — 6000	8.1-130
Phenanthrene	25 — 3000	1.0-380
Pyrene	18 — 4100	ND 19-930

*ND=Not detected.
N/A=Not analyzed for.

Table 80. BACKGROUND CONCENTRATIONS OF TOXIC METALS IN PUGET SOUND BOTTOM SEDIMENTS AND SOILS

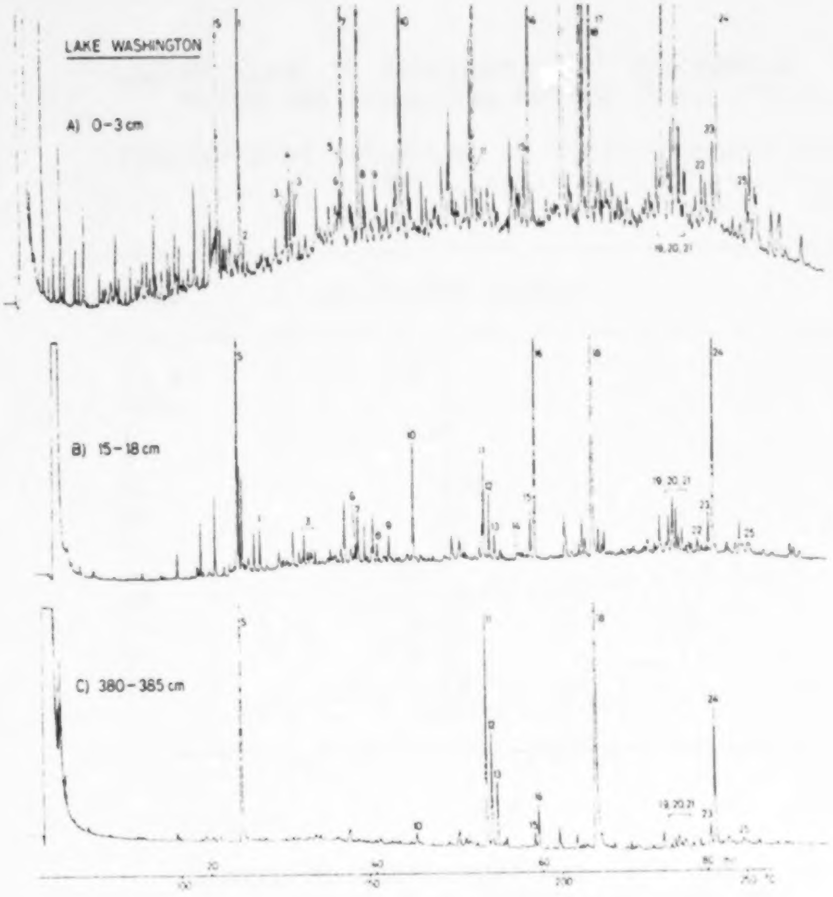
Values are concentrations in ppm=mg/kg (dry weight).
(Dexter et al., 1981)

Metal	Bottom Sediments	Soils
Antimony	1.5	< 15
Arsenic	18	<100
Beryllium	0.4	1
Cadmium	3	7
Chromium	101	80
Copper	35	20
Lead	21	15
Mercury	0.06	--
Nickel	42	80
Selenium	<1.5	--
Silver	1.9	<0.7
Zinc	87	80

Table 81. PRE-1900 CONCENTRATIONS OF METALS IN LAKE WASHINGTON SEDIMENTS

Values are mean (and range) concentrations in ppm=mg/kg.
(Spyridakis and Barnes, 1976)

Metal	Concentration in ppm mean (range)
Copper	17 (10-35)
Lead	12 (6-20)
Zinc	59 (35-84)



Peak Number	Compound
1	Phenanthrene
2	Anthracene
3	Methylphenanthrenes[b]
4	4,5-Methylenephenanthrene[c]
5	Dimethyl/ethylphenanthrenes
6	VIII Pimanthrene (1,7-dimethylphenanthrene)
7	Fluoranthene[c]
8	V 1,2,3,4-Tetrahydroretene (1-methyl-7-isopropyl-1,2,3,4-tetrahydrophenanthrene)
9	III Simonellite (1,1-dimethyl-7-isopropyl-1,2,3,4-tetrahydrophenanthrene)
10	VI Retene (1-methyl-7-isopropylphenanthrene)
11	Isomer of XXIII/XXIV
12	XXIII 3,4,7,12a-Tetramethyl-1,2,3,4,4a,11,12,12a-octahydrochrysene
13	XXIV 3,3,7,12a-Tetramethyl-1,2,3,4,4a,11,12,12a-octahydrochrysene
14	XXIX 1-Methylisopropyl-7,8-cyclopentenophenanthrene
15	XXV 3,4,7-Trimethyl-1,2,3,4-tetrahydrochrysene
16	XXVI 3,3,7-Trimethyl-1,2,3,4-tetrahydrochrysene
17	3,4-Benzopyrene[c]
18	Perylene
19	Isomer of XV/XVI
20[d]	XV 1,2,4a,9-Tetramethyl-1,2,3,4,4a,5,6,14b-octahydropicene XIX 1,2-Dimethyl-1,2,3,4-tetrahydropicene
21[d]	XVI 2,2,4a,9-Tetramethyl-1,2,3,4,4a,5,6,14b-octahydropicene XX 2,2-Dimethyl-1,2,3,4-tetrahydropicene
22	XXX 7-Methyl-3'-ethyl-1,2,-cyclopentenochrysene
23	XVII 1,2,9-Trimethyl-1,2,3,4-tetrahydropicene
24	XVIII 2,2,9-Trimethyl-1,2,3,4-tetrahydropicene
25	XVII 2,9-Dimethylpicene
S	Internal standard

Figure 24.

PAHs IN LAKE WASHINGTON SEDIMENT

Approximate core section ages are A: 1975; B: 1980, C: 3000 years BP. Capillary gas chromatogram is from Wakeham et al. (1980b). Compare with Figure 22.

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D. CONTROL MEASURES AS BEST MANAGEMENT PRACTICES

(Tables and figures for this subsection begin on page 3-135.)

SUMMARY

Street Sweeping

- The priority pollutants in street dust tend to be associated with the small-size fractions (<500 microns).
- Commonly-used street sweeping equipment is relatively ineffective at removing the smaller dust particles.
- Street sweeping appears to have no significant effect on priority pollutant concentrations in stormwater runoff.

Detention Basins

- Most detention basins reduce stormwater velocities but not enough to affect suspended sediment transport.
- Specially-designed dual-purpose detention basins allow settling of suspended material.
- Currently a lack of data exists on priority pollutant removal effectiveness.

Retention or Infiltration Basins

- Although data are limited on priority pollutant removal effectiveness, they generally indicate that while metals are filtered out within the first few meters, some of the more volatile organic compounds may migrate into underlying groundwater.

Wetlands and Grassy Swales

- While wetlands have demonstrated their ability to remove metals and organics from waters passing through them, the chronic effects of such toxicant accumulation are not well understood.
- Grass-lined channels can be very effective at removing particle-bound toxicants from runoff, but need periodic maintenance to remove accumulated sediments.

Oil and Grease Separators

- Most small T-outlet traps have proven ineffective at removing oil and grease from runoff without a high frequency of maintenance.
- Coalescing plate filters may be effective at oil and grease reduction, but no data are available for relatively low concentration runoff applications.

1. Street Sweeping

A statistical examination of priority pollutant concentrations in stormwater runoff showed no significant difference between samples taken from Bellevue's swept and unswept basins (see Tables 9 and 31). This agrees with the preliminary conclusions of the Bellevue Street Sweeping Demonstration Project (Pitt et al., 1981) and the five other NURP cities studying street sweeping (EPA, 1982c; Pitt, personal communication). These results appear to be based on two significant findings: first, the toxic metals and organics are associated primarily with the fine particles (<500 microns), and second, that street sweepers have a limited effect on removing these same fine particles, and may actually increase them through surface abrasion and large particle fractionation (Pitt et al., 1981; Shaheen, 1975; Sartor et al., 1974).

Several studies have examined the relationship between street dust particle size and the associated priority pollutant concentrations. These are reviewed in the earlier section on street dust. More than 75% of most metals in street dust are associated with particles less than 500 microns in diameter (Shaheen, 1975; Pitt and Amy, 1973). Table 82 presents the median particle sizes that the metals are most commonly associated with (from Pitt, 1979); these medians tend to be $\leq$ 200 microns.

Tables 83 and 84 show the removal efficiencies for street sweepers as a percent of total metal removed and as a function of particle size, respectively. A number of variables will affect the efficiency of any street sweeping operation, including the type and condition of the street surface, the total particulate loading and particle-size distribution (generally the lighter the loading, the smaller the mean particle size), the wetness of the surface (increased particle-surface adhesion), and obstacles such as parked cars.

Pitt (1979) found that smoother street surfaces had a higher percentage of fine particles, and that, as the mean particles size was reduced by street sweeping, the pollutant concentrations increased. This finding is reflected in the data reported in the street dust section; i.e., that the concentration of metals tends to be highest in the finer particle-size classes. As the street sweeping removes the coarser size fractions, the net concentration of metals in the street dust increases.

2. Detention Basins

Most detention basins in use for runoff control are designed to hold the peak stormwater flows and release them gradually to the drainage system. They are generally designed for quantity (peak flow) control without consideration for quality, and are often small, deep box structures unsuited for fine sediment control.

A special type of structure is the dual-purpose detention basin, a stormwater control structure specifically designed to both reduce the rate of flow of the runoff and store it long enough to allow deposition of some of the fine suspended material. Stormwater entering the basin is trapped and ponded before it exits through a low-volume overflow channel. The mean depth of many detention basins recently constructed is between three and ten feet (Whipple and Hunter, 1980). As the velocity of the incoming stormwater slows and its energy dissipates, suspended solids tend to settle to the bottom. Whipple and Hunter (1980) reported that, for the dual purpose basins they examined, over 50% of the suspended solids had been deposited after four hours and over 90% after 32 hours.

Recent studies show that settling rates of different pollutants vary considerably from those of the total suspended solids; Whipple and Hunter (1980) reported a 90% particulate matter removal after stormwater had been detained for 32 hours, but found only 70% removal for the hydrocarbons and lead, 50% for copper and nickel, and 40% for zinc.

Urban ponds and lakes can function as another special class of detention basins. Besides being visual amenities and recreational sites, they can be designed to serve as dual purpose basins, removing suspended particles from excess runoff. In a 5.7 acre lake (average depth = four feet) in Missouri, Olivier and Grigoropoulos (1981) found a significant improvement in quality of stormwater after passing through the lake, where the average residence time was 28 days. For an average storm, org-N, COD, total P and TSS concentrations decreased by 31%, 52%, 65% and 89%, respectively, with similar declines in quantities discharged. No toxicants were analyzed.

Several detention basins studies are currently underway as part of the NURP projects in other parts of the country, as well as a local study by the University of Washington (Lettenmaier, personal communication). These should prove to be valuable additions to the current limited knowledge of detention basin toxicant removal efficiencies.

3. Retention or Infiltration Basins

Rather than holding the stormwater for gradual discharge into the receiving waters as is done in detention basins, an alternative strategy is to channel the runoff into a large basin (generally larger than a detention basin) with a highly permeable bottom. The water is contained until it can infiltrate through the soil and eventually enter the groundwater system. These retention or infiltration basins are being used successfully by several municipalities across the country, but data on toxicant removal efficiencies and groundwater contamination problems are limited.

Nightingale (1975) examined the system used by Fresno, California, in which a series of grass-lined depressions, some as deep as 25 feet, received stormwater for storage and groundwater recharge. He studied the soil's ability to filter out suspended particulate matter and retain a number of toxic metals. Results indicated that nearly 100% of the fine particles were retained within a few meters of the surface and lead, zinc, and copper were reduced to background concentrations within the first 15 to 30 centimeters.

The only other information we could find pertinent to retention basins was a report by Hang and Salvo (1980) which referenced studies of the stormwater recharge basins on Long Island, New York, by Salvo (1976), Slimak and Harris (1976), and Seaburn and Aronson (1974). The latter study found that the "uppermost layers of soil" in the recharge basins trapped much of the TOC and pesticides in runoff; TOC concentrations dropped from 13 to 23% of the soil at the basin floor to 1.5 to 3.5% at a depth of 10 centimeters. Salvo (1976) used GC analyses to characterize runoff influent to, and groundwater under, two recharge basins. He concluded, according to Hang and Salvo, that surface adsorption and biodegradation "efficiently inhibit the recharge of stormwater hydrocarbons," although one of his groundwater samples showed a similar pattern to the runoff influent. Slimak and Harris (1976) used GC/MS to characterize runoff and recharged water and concluded, according to Hang and Salvo, "that recharged stormwater is a major source of toxic chemical contamination (to groundwater) on Long Island." Seventeen organics were "identified positively" in the runoff and fourteen (ten overlapping) in the groundwater percolate; ten were common to both sample types. These results are shown in Table 85.

4. Wetlands and Grassy Swales

Research has shown that wetlands function as natural water filtration and purification systems. For stormwater toxicant removal, one of the most valuable features of this system is the wetland's ability to trap suspended solids (as much as 94%; Hickok, 1980). This sediment removal is accomplished by one of three basic mechanisms: water velocity reduction as channel flow changes to street flow, the filtering effects of the vegetation, and finally, electrochemical flocculation effects (SAI, 1979). While very little has been written on the specifics of the electrochemical processes, Lee et al. (1976) reported that plant-produced macromolecules could promote the agregation and sedimentation of clays, organic complexes and a variety of hydrophobic molecules. Wetlands have demonstrated their ability to retain oils, as well as chlorinated hydrocarbons and other synthetic organics (Clark and Clark, 1979; Lee et al., 1976). However, the longterm concentration of these compounds and heavy metals in the "natural filter" wetlands, and their potential bioaccumulation, has not been addressed.

Grassy swales or grass-lined channels function in much the same way as wetlands. The University of Washington's highway runoff study (Want et al., 1981) documented significant removals of TSS and metals in grass channels, as shown in Figure 25 and Tables 86 and 87. In his review of urban erosion control techniques, Highfill (1980) noted, "an eight-foot filter strip can trap as much as 80% of the fine sediments (<0.002 mm)." These toxicant-rich particles accumulate in the channels, as documented by Wang et al. (1981) and shown in Figure 26. Periodic maintenance is required to remove the accumulated materials in order to prevent a delayed release of most or all of these particles in a later runoff event.

5. Oil and Grease Separators

As documented in earlier sections, oil and grease are major contaminants in urban runoff, or, rather, are standard general measures of a range of pollutants in runoff water. Concentrations of around 10 ppm are common in residential runoff, while concentrations over 40 ppm characterize freeway runoff. The oil and grease water quality parameter includes natural organic compounds such as fatty acids from trees and other biological sources, but is composed mostly of hydrocarbon products from lubricating oils and other automotive, anthropogenic sources (Eganhouse and Kaplan, 1981). While direct correlations have proven difficult to establish (Zawlocki, 1981), oil and grease may contain many of the lighter-weight organic contaminants found in runoff.

Ways to separate oil and grease from runoff have been explored, but no direct documentation of their effectiveness in field tests could be found in the literature. Lettenmaier and Dally of the University of Washington's Department of Civil Engineering are currently studying detention systems including the oil and grease separator of the Metro Transit East Operating Base in Bellevue (Lettenmaier, personal communication). Data should be available in 1983.

Typical oil and grease traps, as shown in Figure 27, contain a "T"-outlet which excludes floatables. To be effective, however, the trapped floatables (oil and grease, etc.) in such structures must be removed between each storm event. Without such maintenance, subsequent storms tend to resuspend or re-emulsify the floatables and discharge them through the outlet.

A recent (but expensive) innovation from industrial pretreatment and bilge water control technology is beginning to be applied to stormwater runoff in special high-risk locations. Called a coalescing plate separator, this unit uses packs of corrugated plates (see Figure 28) to coalesce small ($\geq$ 7 um) oil and grease droplets into larger ($\geq$ 20 um) droplets which float more readily and can be skimmed off the top. Fram® product brochures boast removals that produce an effluent containing less than 10 ppm of oil with a single pack unit and less than 5 ppm with a secondary unit. No field test data on urban runoff could be located.

Table 82. MEDIAN PARTICLE SIZES FOR VARIOUS PRIORITY POLLUTANTS (Pitt, 1979.)

Pollutant	Approximate Median Particle Size in Microns
All Pesticides Combined	140
Cadmium	61
Chromium	220
Copper	120
Lead	200
Nickel	230
Zinc	190

Table 83. HEAVY METAL REMOVAL EFFICIENCIES OF STREET SWEEPERS

Values are percent removal by weight. Optimal calculated removals are from Novotny and Chesters (1981); average observed removals in Seattle and in the eight cities studied are from Pitt and Amy (1973).

	Optimal Removals		Average Removals (Mechanical)	
Toxicant	Vacuum	Mechanical	Seattle	National
Cadmium	45%	28%	--	38%
Chromium	53%	44%	49%	56%
Copper	49%	38%	42%	46%
Lead	62%	44%	54%	51%
Nickel	55%	45%	50%	49%
Zinc	55%	43%	48%	49%

Table 84. STREET SWEEPER REMOVAL EFFICIENCY BY PARTICLE SIZE (Pitt and Amy, 1973.)

PARTICLE SIZE	PERCENT REMOVAL
<104μ	17%
104 to 246μ	48
246 to 495μ	55
>495μ	67

Table 85. ORGANIC COMPOUNDS FOUND IN RUNOFF AND RECHARGED GROUNDWATER ON LONG ISLAND, NEW YORK

These results are from GC/MS analyses by Slimak and Harris (1976), as reported in Hang and Salvo (1980).

Compound	Stormwater Runoff	Groundwater Percolate Under Recharge Basin
Benzene	X	X
Toluene	X	X
Ethyl benzene	X	X
Methlyene chloride		X
M-xylene	X	
P-xylene	X	
Ethyl phthalate	X	X
Ethyl hexyl phthalate	X	X
Dioctyl phthalate	X	X
Diethyl phthalate	X	X
Butyl phthalate		X
Methyl-18-methoxy-abiatate	X	
Ethyl benzaldehyde	X	
Methyl palmitate	X	X
Methyl nonanoate	X	
Phenyl eicosane	X	
Methyl myristate	X	X
Methyl tearate	X	X
Squaline	X	X
2-isopropyl-1,3-dioxolane		X
benzyl-2 (benzyl-thio) propionate		X

Table 86. LEAD REMOVAL EFFICIENCIES BY GRASS CHANNELS OF VARIOUS LENGTHS (Wang et al., 1981.)

Channel Length (m)	Predicted Removal Efficiency (Percentage) Mean	95 Percent Confidence Interval
20	59.4	40.9 - 77.9
40	80.5	68.4 - 92.7
60	90.3	82.0 - 98.6

Table 87. GRASS CHANNEL TSS[a], VSS[b] AND COD[c] REMOVAL EFFICIENCIES (Wang et al., 1981.)

Channel Length (m)	Removal Efficiency (Percentage) TSS	VSS	COD
21	90.4	90.9	81.5
43	93.2	86.4	81.5
67	94.5	100	88.3

[a] Total Suspended Solids

[b] Volatile Suspended Solids

[c] Chemical Oxygen Demand

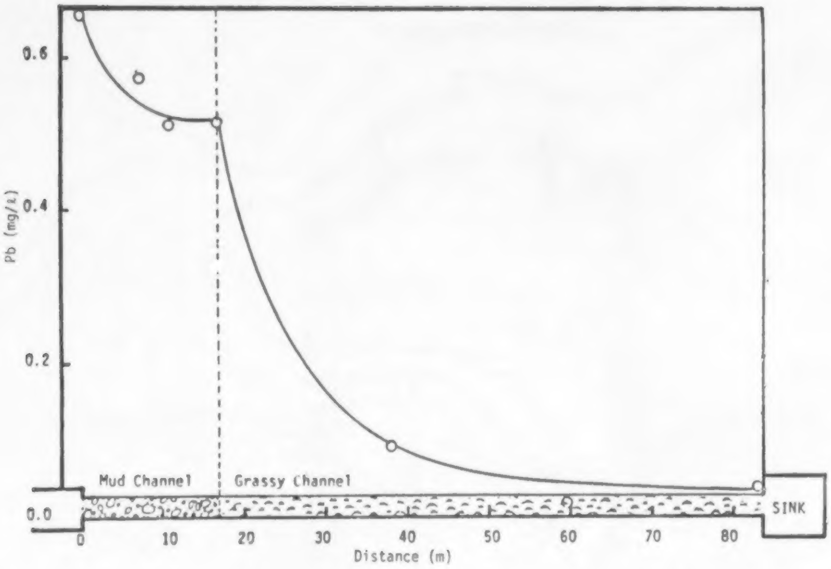


Figure 25.

REDUCTION OF LEAD CONCENTRATION IN HIGHWAY RUNOFF WITH DISTANCE TRAVELED IN MUD AND GRASS CHANNELS

(Wang et al., 1981)

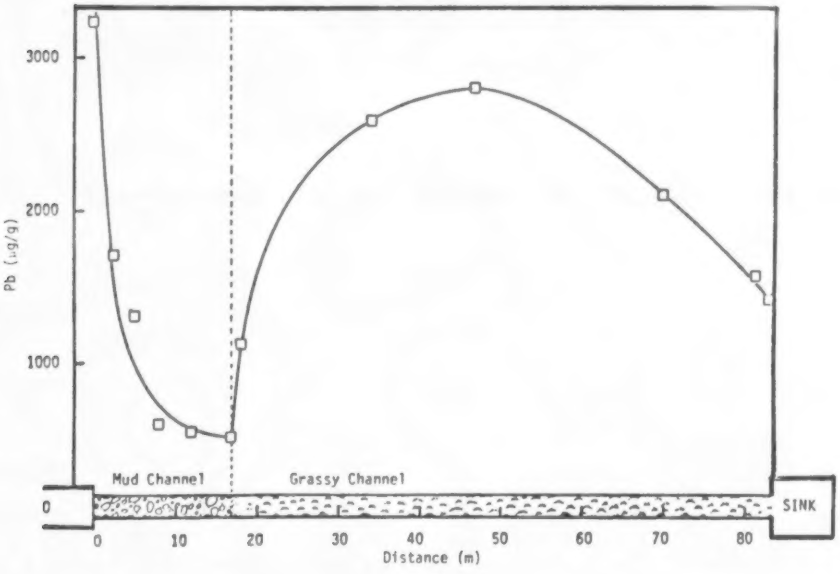


Figure 26.

LEAD CONCENTRATIONS IN UPPER 1 cm OF SEDIMENT FROM MUD AND GRASS CHANNELS RECEIVING HIGHWAY RUNOFF

(Wang et al., 1981)

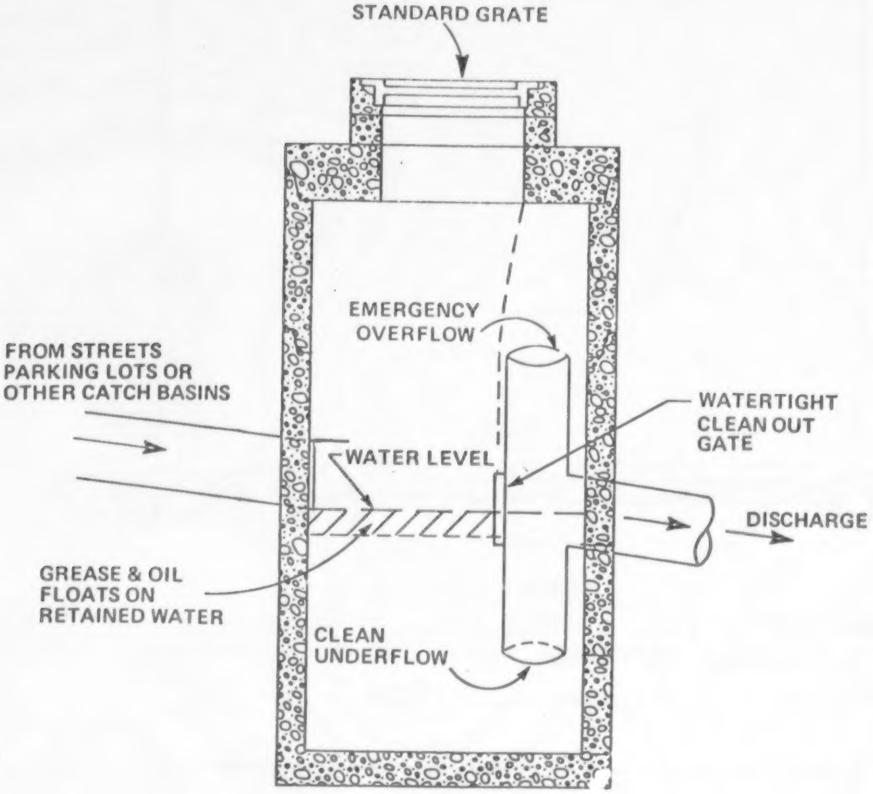

STANDARD GRATE
EMERGENCY OVERFLOW
FROM STREETS PARKING LOTS OR OTHER CATCH BASINS
WATERTIGHT CLEAN OUT GATE
WATER LEVEL
DISCHARGE
GREASE & OIL FLOATS ON RETAINED WATER
CLEAN UNDERFLOW

Figure 27. TYPICAL "T"-OUTLET OIL AND GREASE TRAP

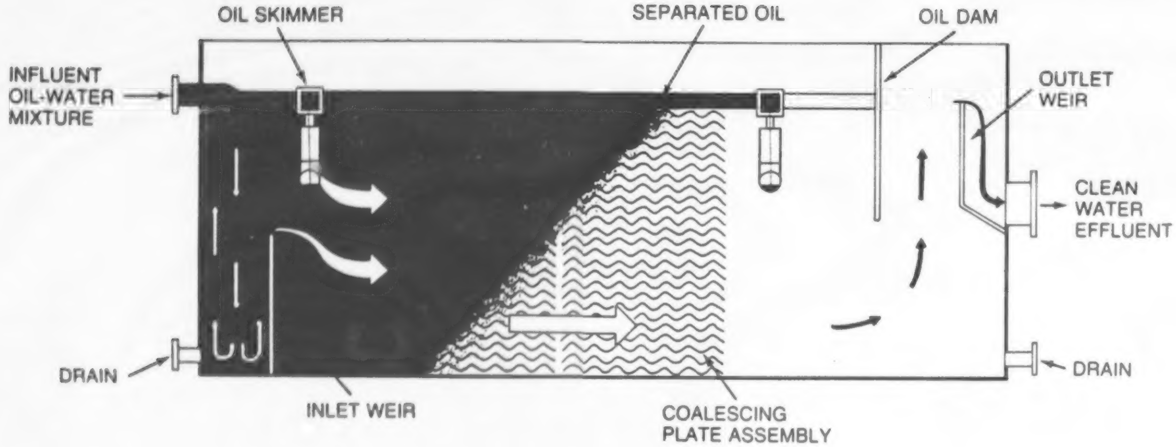

OIL SKIMMER
SEPARATED OIL
OIL DAM
INFLUENT OIL-WATER MIXTURE
OUTLET WEIR
CLEAN WATER EFFLUENT
DRAIN
INLET WEIR
COALESCING PLATE ASSEMBLY
DRAIN

Figure 28.
COALESCING PLATE OIL AND GREASE SEPARATOR
(From Fram® literature.)

SECTION IV

DISCUSSION AND ANALYSIS

A. FOLLOWING THE POLLUTANT PATHWAYS

1. Air

Suspended material in the atmosphere generally occurs in two distinct size ranges, one greater than five microns which originates predominantly from physical abrasion of streets and soils, and the other less than one micron, which originates from combustion, aerosol formation and other processes (Nolan, personal communication). The larger size range, which includes some particles from vehicles exhaust containing lead and other contaminants, tends to fall out fairly close to its source and be a prime component of the fine material -- in street dust, for example. The smaller size range, on the other hand, tends to remain suspended, avoids washout with rain, and eventually forms condensation nuclei for water droplet formation over large climatic areas. What contribution this size range of fine particles makes to local street dust and urban runoff is unclear.

Lead, the most abundant toxic constituent in urban runoff, generally enters the environment associated with the airborne dust and aerosols expelled with vehicle exhausts. While it makes up less than one percent by weight of the total airborne material (Sylvester and DeWalle, 1972), deposition from the atmosphere accounts for as much as 30 to 40% of the total lead loading into the Upper Great Lakes (Slinn and Slinn, 1981) and about one-third of all anthropogenic lead entering the oceans (Forstner and Wittmann, 1981).

Removal of lead and many other pollutants associated with airborne particles occurs through either rainfall, snowfall (scavenging efficiency is greater for snow than for rain due to larger surface area), or dry deposition. Authorities generally agree that precipitation is the most effective process for long-term atmospheric cleansing and is the primary means for transferring the smaller airborne particles to surface waters. Dryfall accounts for the major input of the larger particles to surfaces and runoff waters. Total surface loadings of the two processes may be about the same (Novotny and Chesters, 1981).

Concentrations of metals and PAHs with airborne particles reported in this and other studies are generally in the part per million range. Much of this (because of the high volume filters employed) represents contaminants adsorbed onto the very fine, submicron particles that are not as likely to contribute directly to local street dust and runoff loads.

An example of this phenomenon can be found in Metro's PAH data for airborne particles and street dust. As shown in Table 51, the dominant types of PAHs in these two categories are different. While there is much overlap, the airborne particles tend to contain high concentrations of the larger, three- to five-ring PAHs which are high temperature combustion products. The PAHs in street dust, on the other hand, tend to be the smaller, two- to three-ring compounds which are more likely to originate from used lubricating oil (Farlow, personal communication). Some contribution to the street dust PAHs may come from the regional airborne burden, but the majority probably comes directly from dripping and exhaust fallout onto the road surface from motor vehicles.

Despite the above conclusions, information exists which supports a model of regional air pollutant fallout as a contributor of at least some substances to surface contamination. The major source of arsenic, which was found in Metro's airborne particle, street dust, and stormwater and sediment samples at concentrations higher than in other parts of the country, has been generally credited to the ASARCO copper smelter in Ruston/Tacoma (Crecelius, 1975; PSAPCA, 1981). Winds tend to blow the smelter's plume north and northeast, creating an area in King County with elevated arsenic levels.

Atmospheric deposition has been estimated in this area using airborne particle concentrations and a "total deposition velocity" factor (Crecelius, unpublished data). Calculated deposition rates for lead in the Puget Sound region range from 11 to 52 $mg/m^2/year$.

Local surface contamination "hotspots" have also been documented as originating from air pollution sources. For example, the extremely elevated concentrations of lead in the dust and soil on Harbor Island in Seattle have been credited to the past emissions from the RSR-Quemetco secondary lead smelter located on the island (PSAPCA and DOE, 1980). While current emissions are substantially less than in the past, lead concentrations up to 18% (180,000 ppm) are present in the parking lot dust and soil on the island, and represent the highest concentrations of lead in the Metro area. Sediments off Harbor Island storm drains reflect these high concentrations from runoff transport.

Thus, while some examples of direct connections can be made between air pollution sources and dust or runoff contaminants, the overall contribution of regional air pollutants to runoff and water quality problems is a much speculated-upon, but little documented, factor. We must conclude that high concentrations of many toxicants in air particle samples do not directly implicate atmospheric fallout as a major source of these substances to surface waters. More research is needed in this important area.

2. Street Dust

As the result of both direct deposition and collection of the heavier air- and waterborne particles, street dust often contains the widest variety and highest concentrations of toxic trace substances within the urban environment. The volume of street dust and its toxicant concentrations vary depending upon landuse and amount of impervious surface, area of exposed and erodible soils, meteorological conditions, traffic volumes and velocities, street surface condition, and effectiveness and frequency of street cleaning (Pitt, 1979; Shaheen, 1975).

A study by Hopke et al. (1980) based on metals analysis of highway dusts listed the following as primary components of their samples: soils (76%), iron as rust (7.7%), tire and brake wear material (7.2%), concrete dust (5%), engine exhaust particles (1.5%), various salts (0.3%), and unknowns (2.3%). They noted that the soil component contained very high concentrations of lead, indicating probable contamination by, and under-estimation of, engine exhaust constituents.

Sartor and Boyd (1972) found that streets paved with asphalt had approximately 80% higher loadings than those surfaced with concrete. And along with Pitt (1979), they reported that smooth streets in good condition had half the particle accumulation of rough, poorly maintained roads. Their study also noted that over 95% of the street refuse could be found within one meter of the street's curbs due to resuspension and concentration by wind and traffic turbulence.

As documented in the Results section, metals and organics tend to be associated with the finer particle sizes in the street dust. Water running over the street surface is more likely to pick up and carry the fine particles. The finer the particle size, the more suspendable it is in water and the longer it will take to settle out again. Removing the fine particles from the street surface or from the runoff water once suspended, however, is difficult. Street sweeping, for example, tends to collect the larger particle sizes and leave the fine particles behind (or actually increase their numbers by grinding up some of the larger particles). Detention systems, as simple as a catch basin or as complex as the multi-weir, outlet-controlled units often now installed for quantity control, tend to let the sandy-sized solids settle out but do not hold onto the flow for a sufficiently long enough time to let the silt settle out.

3. Runoff

As stormwater flows across the many impermeable surfaces within an urban landscape, it picks up and transports the finer particles, oils, and various water-soluble materials. The more intense the rainfall, the more energy is available for transport. Griffin et al. (1980) found that the fine, insoluble material capable of being carried in suspension exhibited a "first flush" removal pattern (high initial concentrations followed by rapid decline), while the soluble compounds appeared more uniformly throughout the runoff event.

Comparing Metro's values for the principal street dirt metals with its stormwater metal concentrations reveals decreases in concentrations from parts per million to parts per billion -- an average factor of approximately 5,000. This can be attributed to dilution, the relatively low solubility of the toxic metals, and their strong affinity for fine particles, especially if organic in nature.

Because of similar solubility and adhesion characteristics, it is reasonable to assume that the organic toxicants undergo a comparable dilution between dust and stormwater. Because many were in the part per billion range to begin with, a reduction by a factor of a thousand should reduce them to concentrations well below detection limits -- of the 34 organics found in Metro street dust samples, only 21 could be detected in stormwater, and these were very near detection limits.

4. Interstitial Streamwater

The interstitial streamwater samples were thought to contain dissolved and particulate material from natural erosion and organic detritus, as well as stormwater contamination -- whether directly from outfalls or indirectly from runoff. Due to mixing and dilution, we assumed that the concentrations of metal and organic toxicants would show a decrease similar to that between the dust and stormwater. Instead, mean concentrations of metals were generally found to be two or more times higher in the interstitial samples than in the stormwater (the only interstitial organic -- benzene -- was at similar concentrations in both).

The collection method of pumping the water out of the perforated standpipe with a Manning sampler involved a purge phase in which water was expelled back through the collection tube. This created considerable turbulence within the standpipe and a high degree of turbidity for all interstitial samples. Possibly because the interstitial water samples contained such high volumes of suspended particles, contaminant concentrations were artificially elevated. Stormwater samples generally showed less turbidity. Richey (1982) found that samples from these same standpipes had virtually all the interstitial lead associated with the particulate matter; any soluble fraction was below detection limits (4 ppb).

5. Stream Sediments

Numerous researchers investigating the transport of priority pollutants through the environment have concluded that most of the metal and organic toxicants are either in the form of fine particles or are tightly bound to them. Hopke et al. (1980) noted that most auto exhaust components are associated with particles which settle out of the air rapidly on or near the road surface. Wilber and Hunter (1979) found that, on the average, less than 1% of the total metals detected were soluble in freshwater with a pH of 7.4. Neff (1979) reports: "Because of their low aqueous solubility and hydrophobic character, PAHs readily adsorb to particulate materials and solid surfaces in water."

Because the sediments are the repository for all particles no longer carried in suspension, the various size ranges of cobbles, gravel, sand, and mud which enter or move in the stream are sorted and deposited according to the energy of the stream system. This accumulation of fine organic and inorganic particles is rarely longterm, however. With each major storm, high velocity flows scour much of the channel, moving the finer material downstream until it collects again in pools, eddies, wetlands or receiving waters such as Lake Washington (Richey, 1982).

Metro's examination of stream sediments attempted to quantify the toxicant buildup, if any, and examine its characteristics. A comparison with the concentrations of metals in our street dust samples found that they ranged from two times (for arsenic and nickel) to as high as 500 times (for lead) greater than the stream sediment values. Concentrations of stream sediment metals were very similar to reported average concentrations for the trace elements in crustal rocks and soils (see Table 56). This suggests that within the stream beds, dilution had reduced most stormwater-borne metal concentrations to background levels; however, arsenic in every case and lead, cadmium, chromium, and zinc in some cases appeared elevated. A significant difference existed between urban and non-urban streams -- the urban streams, as expected, carried the higher concentrations of toxic material in their sediments.

Except for a few of the PAHs (e.g., perylene and phenanthrene), most toxic organic compounds have no natural background levels, so any detectable concentrations indicate contamination. The phthalates and PAHs generally followed the pattern of reduction in concentrations from road dust to stream sediments in ranges from 100 to 1,000 times. But the levels of the phenols and benzene-toluene groups in the stream sediments were found to be equal to or greater than concentrations in road dust. Possible explanations include contamination of the streams by gasoline or other petroleum solvents either through runoff (these compounds are quite soluble), or by direct spillage. They both have high affinities for fine organic or clay sediments (Callahan et al., 1979). The most likely explanation for the phenol values is the analytical contamination found in the quality control testing (see Appendix A).

6. Lake Sediment

As the receiving body for sediment transported from the sampled streams, Lake Washington represents the final link in this priority pollutant pathway study. In addition to these and several other streams, the Cedar River and Sammamish River flow into the lake and form its primary sources. The lake's U-shaped basin has a maximum depth of about 60 meters and a water residence time of about three years, allowing most incoming suspended particles to settle out (Wakeham and Carpenter, 1976).

The relatively uniform distribution of toxicant concentrations found at the various sampling sites coincides with those reported for aliphatic hydrocarbons by Wakeham and Carpenter (1976) and confirms Tomlinson et al.'s (1980) findings that the fine particles discharged by storm drains and combined sewer overflows do not settle out directly off the discharge points but rather contribute to the overall lake sediment burden. The fine, toxicant-laden particles appear to be well mixed before settling. Gould and Budinger (1958) found that winter convective currents redeposit large areas of the lake's surface sediments, reducing local sedimentation buildup.

As with the stream sediments, many of this study's metal concentrations appear within the range of natural background trace elements; however, arsenic, copper, lead, mercury, and zinc concentrations were elevated in at least a few samples. The PAHs and volatiles also have concentrations similar to those in stream sediments but the Lake Washington sediments contain pesticides previously undetected in the streams.

B. TOTAL TOXICANT CONCENTRATIONS VERSUS BIO-AVAILABILITY

As mentioned in Part D of the Introduction, the EPA established federal toxicity criteria for metals based on concentrations of free metallic ions lethal to sensitive aquatic organisms (Sittig, 1980). But in the natural environment, very little of any toxic metal is available in the free ionic form. In an attempt to measure the biological availability of the five most commonly detected toxic metals (lead, zinc, copper, nickel, and chromium), Wilber and Hunter (1979) measured their solubilities from freshwater particles and sediments (pH 7.4) and found, on the average, less than 1% of the metals were soluble. To test for ion-exchangeability they exposed the metals to ammonium acetate (pH 7.0). Maximum ionic availability increased to an average of 6% for lead, 14% for zinc, 15% for copper, 16% for nickel, and 1% for chromium.

The conclusion, as pointed out by Florence (1977), is that, unless correctly interpreted, the total metal concentration measurement can provide misleading results. A water sample with a high total metal concentration may actually be less toxic than a second sample having a lower total concentration if the second sample has more of its metal biologically available in the dissolved, ionic form.

The organic priority pollutants do not need to be ionized to be toxic, but due to their variety of characteristics including solubility and fine particle adhesion, biological availability can be difficult to determine. In examining one of the most commonly found groups of organics, Neff (1979) noted that the concentrations of soluble PAHs usually represent only 2 to 16% of the particulate concentrations; and studies on bio-availability from food and sediments indicate that PAHs complexed to colloidal organics or adsorbed to fine particles are less bio-available than PAHs in solution.

Detection of trace levels of metals or organics in water and sediments thus presents difficulties in interpretation. Widely varying results have been reported in the literature for "soluble" fractions of metals, because of operational definitions based on filter-size and analytical detection limits, as well as real differences in hardness and pH. Varying results also are found on toxicity bioassays. Portele (1981), for example, reported toxic responses in algal, zooplankton and fish tests from highway runoff. Other studies have found no toxicities in runoff or urban stream samples.

Ambient water concentrations that exceed federal criteria certainly are cause for concern, but the adhesion of most of these detected substances onto suspended particles and the uncertainties of soluble concentrations make questionable their bio-availability. More definitive local studies of toxicities and available concentrations are urgently needed.

No criteria are available for comparison with sediment concentrations. Elevation of metals above background concentrations is common in urban sediments, but the point at which these elevated concentrations present problems to the aquatic biota is unknown. Sediment bioassay tests are necessary for these determinations, but data are scarce. Recent tests using amphipods (Metro, unpublished data) show some mortalities in sediment samples from Elliott Bay and Puget Sound, but causal factors are unknown. Ongoing research by NOAA (Malins et al., 1982) of fish pathophysiology in the Pugest Sound area has documented elevated numbers of tumors and other adnormalities among bottomfish in urban embayments which correlate with general toxicant burdens in the sediments; but again, causal agents are as yet undetermined.

While sediments are generally viewed as a sink which accumulates the contaminants found associated with waterborne particles, recent studies of resuspension (e.g., Seelye et al., 1982) point to a greater chance for availability of some sediment contaminants than previously thought. Much more work needs to be done in this area.

Answering the question, "So you see trace levels of some metals and organics in runoff and the environment, but are they a problem?" has proven to be the greatest challenge and biggest unknown for this project.

C. PRIORITY POLLUTANTS OF SPECIAL INTEREST

A small number of priority pollutant metals and organics has consistently been reported in association with stormwater and its receiving bodies either with high percentages of occurrence, high concentrations, or both. The following summaries were prepared in order to provide a concise source of background information on their common origins, chemical forms and probable fates, as well as reported toxicity levels.

1. Lead

In Metro's street dust and urban stormwater samples, lead appeared at higher concentrations than any other priority pollutant. It most often enters the environment from exhaust residues of gasoline anti-knock compounds; in the U.S., discharges from the breakdown of auto emissions form the single largest source of lead pollution (Forstner and Wittmann, 1981). Dispersal of other lead compounds results from tire abrasion (lead in rubber compounds), from paint and primer pigments, from wind- and water-carried smelter wastes and portland cement production, and from soft water leaching of solder joints on copper pipes, or stabilizers (lead stearate) in some plastic pipes (Callahan et al., 1979; EPA 1980a).

Once deposited with the road dusts and adjacent soils, over 80% of the lead salts form highly stable and insoluble associations with the various carbonates and iron or manganese oxides (Harrison et al., 1981). Most of the remainder forms complexes with naturally-occurring organic acids which increase lead's adsorptive affinity for fine mineral particulates (Callahan et al., 1979). Solubility of these lead compounds depend on the water's acidity, ranging from about 10,000 ppm at pH 5.5 to one ppb at pH 9.0 (Sittig, 1980). Sylvester and DeWalle (1972) found that fine suspended particles scavenge ionic lead from the water column in receiving bodies.

The federal ambient water quality criteria are based on exposure tests using soluble inorganic salts of lead, generally lead chloride and lead nitrate (EPA, 1980a). As mentioned in the preceding section, these criteria were made deliberately conservative and do not reflect most naturally occurring toxicity thresholds. Most studies have indicated that, because of their low acidity and high suspended material content, the majority of natural waters render lead compounds unavailable for assimilation by aquatic organisms (Callahan et al., 1979).

Some bacteria, as well as oysters and mussels, are capable of accumulating relatively high levels of lead due to their internal concentration of fine particles while feeding. In addition, small amounts of lead may be remobilized from bed sediments due to biomethylation by benthic microbes. Scott et al. (1982) report adverse effects to salmonid alevins in soft water at dissolved concentrations of 250-500 ppb.

2. Zinc

Zinc is one of the most abundant trace metals and occurs naturally in small concentrations in virtually all water bodies. It never appears in mineral form as a pure metal but instead as the sulfide, oxide, or carbonate (Sittig, 1980). Except in very soft, acidic water, these compounds are relatively insoluble.

Of the numerous sources of anthropogenic zinc to the urban environment, the weathering and abrasion of galvanized iron and steel are potentially the largest. Other major contributors include the use of zinc oxide in vulcanizing and binding tire rubber (as high as 1.5% by weight), and as a component of lubricating oils (1,500 ppm). Some secondary sources include asphalt (160 ppb), brass (copper plus zinc), and portland cement production (Perwak et al., 1980; Shaheen, 1975; Forstner and Wittmann, 1981).

In road dust, the speciation pattern for zinc resembles that of lead; the insoluble carbonate and Fe-Mn oxide compounds represent more than 60% by weight. Samples of river, estuarine, and nearshore sediments display the same pattern (Harrison et al., 1980).

Most ionic zinc is quickly removed from streamwater by adsorption to clays or hydrous iron and manganese oxides, and, to a lesser degree, by organic particles. Zinc concentrations in the suspended solids and sediments are typically found in the part per million range while concentrations of zinc ions in the water column are in the low part per billion range (Perwak et al., 1980).

Field observations by Nienke and Lee (1982) described the rapid decrease in zinc concentrations as contaminated tributaries entered and mixed with the waters of Lake Michigan. They found that virtually all of the incoming zinc was strongly sorbed onto inorganic and organic particles and transported to the sediments. The higher the water's turbidity, the more effective the scavenging. Nienke and Lee concluded that this essentially irreversible sorption of zinc by aquatic sediments makes it unlikely that aquatic organisms will receive even a chronic toxicity exposure.

Not everyone agrees that zinc in runoff is biologically unavailable. Shaheen (1975) found zinc was the most soluble of any metal measured in stormwater runoff. Portele (1981) examined runoff from three highways in the Seattle metropolitan area and concluded that the concentrations of soluble zinc observed in runoff correlated well with observed toxic responses in algae, zooplankton, and fish.

For Metro's samples, street dust and stormwater concentrations of zinc were approximately half those for lead; but in the interstitial water and stream sediment samples, zinc exceeded lead concentrations by from two to ten times. In the Lake Washington sediment samples, their average concentrations for all sites were identical. Wilber and Hunter's (1979) study in Lodi, New Jersey found similar results for street dust, stormwater, and river sediment concentrations.

With a few noted exceptions, research on the toxic effects of zinc in the aquatic environment has generally found that its various inorganic and organic associations are not available to aquatic organisms (Nienke and Lee, 1982; Perwak et al., 1980). When the free ion is available due to low pH and lack of adsorptive materials, several studies have found that most plants and invertebrates are not sensitive to zinc in concentrations less than one part per million (Perwak et al., 1980).

While rainbow trout have shown an avoidance response to ionic concentrations as low as 5.6 ppb and acute effects at 90 ppb (EPA, 1980a), in a study by Chapman (1978), concentrations of zinc as high as 350 ppb produced no adverse effects on survival, fertility, fecundity, growth, or smolt survival of sockeye salmon during an 18-month exposure. Perwak et al. (1980) note that acclimation greatly reduces an organism's sensitivity to zinc exposure, a phenomenon common for other contaminants as well.

No carcinogenic or mutagenic effects have been reported for zinc. While it is concentrated by some organisms, it is not biomagnified up the food chain (Perwak et al., 1980). Zinc is an important plant and animal nutrient in trace amounts.

3. Copper

For a trace metal, copper is relatively abundant in the earth's crust and occurs naturally in low concentrations in most fresh and saltwater bodies. Ambient concentrations are usually well below 20 ppb (Sittig, 1980). Mineral copper usually occurs as sulfides and oxides but can exist as the pure metal.

While the majority of all refined copper is utilized for electrical wiring and equipment, such use is probably an insignificant source to urban runoff. Leaching and abrasion of copper pipes and brass fittings, deposition with used motor oil (3 ppm; Shaheen, 1975), and wear from vehicle parts (brakes, alternators, radiators, etc.) probably represent the primary sources. Copper is also frequently used as an aquatic algicide ($CuSO_4$) and as a wood preservative (Perwak et al., 1980).

After reviewing current studies, Perwak et al. (1980) concluded that copper entering the aquatic environment from stormwater transport is probably already adsorbed onto soil and organic particles. Harrison et al. (1981) found copper in street dusts principally associated with organic materials and the same pattern appeared in aquatic sediments. They noted that copper displayed less mobility and bioavailability than either lead or zinc. However, the NURP "special metals" study (EPA, 1982d) found copper to be present more often in the dissolved fraction of runoff (passed through 0.45 micron filter) than either lead or zinc. Portele's (1981) highway runoff study found copper in soluble form and possibly responsible for observed toxicities.

In pristine streams with neutral pH values, most copper in solution is present as forms of cupric carbonate, but in waters with suspended organic material, humic complexes adsorb almost all available copper. This organically complexed copper is more easily adsorbed to clay particles than is the free ion; thus the typical fate of nearly all dissolved copper will be either inorganic or organic complexing and sorption onto fine particulate and sediment material (Callahan et al., 1979; Florence, 1977).

Hollibaugh et al. (1980) state that the toxicity of copper to various species of phytoplankton was a function of the cupric (Cu^{+2}) ion rather than the total available concentration of copper. Only about 1% of the copper was present as the free Cu^{+2} ion in sites they examined. Perwak et al. (1980) flatly declare that copper, whether as organic complexes or adsorbed to particles, does not appear to be available to aquatic organisms. They also found that, in general, ionic copper comprises less than 1% of total measured copper. Releases of concentrated dissolved copper were rapidly diluted, precipitated, or adsorbed onto particles allowing return to baseline values within 24 hours.

Thomas et al. (1980) prepared bioassays with copper at concentrations approximating conditions in a moderately polluted estuary. The natural varieties of phytoplankton showed no demonstrable effects. On the other hand, Hollibaugh et al. (1980) reports that, in the ionic form, copper is more toxic to phytoplankton than any other ionic metal except mercury.

As with zinc, ionic copper is an important trace nutrient, so can be readily accumulated by most organisms if available in subtoxic concentrations. It has not been found to biomagnify up the food chain and shows no carcinogenic or mutagenic tendencies. For many organisms, low dosage acclimation has been shown to increase tolerances to higher concentrations (Perwak et al., 1980).

4. Nickel

As a crustal mineral, metallic nickel is seldom found and, along with its common carbonate and sulfide salts, is highly insoluble. Other salts, however, are quite soluble, especially the chlorides, nitrates, and sulfates.

Nickel forms a common trace component of natural freshwaters, usually in concentrations less than one ppb. The major reason for these naturally low levels is nickel's tendency to bind with hydrous iron and manganese oxides and suspended organics. But while sorption and precipitation play a significant role in aquatic entrapment and removal, they do not seem to affect nickel to the same degree as for most other trace metals, making it one of the more mobile and relatively more stable minerals in the ionic form (Callahan et al., 1979).

Cultural sources of nickel include: its extensive use as an alloy in stainless steel and other metal plating (Sittig, 1980), used motor oil at levels as high as 17 ppm (Shaheen, 1975), and the burning of fuel oil and coal (Forstner and Wittmann, 1981). Wilber and Hunter (1979) reported that less than 7% of the nickel detected in stormwater was either in the ionic or ion-exchangeable form.

Nickel is an essential trace nutrient; Hollibaugh et al. (1980) stated that in their bioassays, nickel appeared to stimulate the growth of some test organisms. It is not generally bio-concentrated, nor does it magnify up the food chain. The toxicity of ionic nickel is decreased by increased water hardness. In soft water ($CaCO_3$ levels of 50 mg/l) rainbow trout showed chronic (96 hour) effects at nickel concentrations of 350 ppb (EPA, 1980). Nickel is neither a carcinogen, nor a teratogen (Sittig, 1980).

5. Chromium

For a trace metal, chromium is relatively abundant in the earth's soils and crustal material (see Table 65). In aquatic systems, chromium exists in one of two dissolved ionic forms: +3 (Cr III) or +6 (Cr VI); neither appear to be affected by water hardness. The Cr VI oxidation state is highly soluble and is not readily sorbed to clays or hydrous metal oxides (although it may have an affinity for organic materials). It is as much as 100 times more toxic than ionic Cr III (EPA, 1980a).

Fortunately for aquatic life, over 90% of the dissolved chromium in receiving waters is in the Cr III form. This ion will quickly react with aqueous hydroxide ions to form insoluble chromium hydroxide which precipitates to the bottom sediments. Because Cr VI is a strong oxidizing agent, it will often react to form Cr III (Callahan et al., 1979). Wilber and Hunter (1979) found less than 1% of the chromium in stormwater and river sediments was biologically available. Because the Cr III ion is an essential trace nutrient, some will be bioaccumulated. Hollibaugh et al. (1980) found that low concentrations of Cr III stimulated growth in some bioassay tests.

Chromium can enter the environment through its uses in metal plating, as paint pigments (especially the chrome yellow in road striping), as an antifungal agent in cooling waters, and in some wood preservatives.

6. Arsenic

As a mineral, arsenic occurs worldwide but generally only in minute amounts. It is usually in the form of the inorganic arsenate (AsO_4^{-3}). Despite the arsenate ion's high solubility, its aquatic concentrations are very limited due to removal of free ions by adsorption to metal oxides and sulfides, clays, alum, and organic particulates. Of the arsenic transported by rivers, only 3 to 4% was found to be bio-available (Callahan et al., 1979). Crecelius (1975) estimated that 55% of the arsenic entering Lake Washington was deposited in its sediments.

Researchers across the country have reported finding arsenic in stormwater runoff at trace levels. The preliminary results of the Nationwide Urban Runoff Program (U.S. EPA, 1982c) listed the four priority pollutants with the highest frequency of detection as zinc (100%), lead (93%), copper (91%), and arsenic (58%). Metro's results for the Bellevue project showed consistently the highest concentrations of arsenic of the 28 NURP cities.

Because of a general lack of detailed data, little is known about the specifics of arsenic's toxicity to aquatic organisms. Arsenic probably acts as an essential trace nutrient and is found in all living organisms (EPA, 1980a). Organisms display a wide range of sensitivity. Early life stages and low-complexity life forms usually show the lowest tolerances.

While there is a limited amount of bioaccumulation, no biomagnification has been observed. Inhalation of arsenic dusts has been linked to cancer in humans, but no animal carcinogenicity has been demonstrated (Sittig, 1980), and the health hazard of ingestion or aquatic exposure is controversial.

Most toxicity tests were conducted with sodium arsenite, an aquatic herbicide and agricultural pesticide used extensively in the U.S. until 1967 (Novotny and Chesters, 1981) and reported by some researchers to be the most toxic form commonly encountered (Callahan *et al*., 1979). Organic arsenic compounds appear to be much less toxic (EPA, 1980a).

The soils, surface waters, and sediments of the Metro study area show unusually high concentrations of arsenic due to the stack emissions from the ASARCO copper refinery in Ruston/Tacoma (Crecelius, 1975; Callahan *et al*., 1979; PSAPCA, 1981). Other potential nonpoint sources include coal-fired power plants, portland cement processors, and its use in glass, cloth, and electronic parts manufacturing.

7. Cadmium

Considerably fewer nonpoint sources exist for cadmium than for most of the other trace metals. It is commonly used in electroplating metals, as a pigment in some paints, in certain plastics as a stabilizer, and in nickel-cadmium batteries. Cadmium is released to the atmosphere during the burning of coal and fuel oil.

Cadmium has both soluble and insoluble salts; when it does dissolve in water, it forms a +2 ion. While cadmium is less affected by sorption than most other metals, in soft waters with low levels of suspended particulates its ions can combine with carbonates and iron oxides to precipitate to bottom sediments (Callahan *et al*., 1979). In more turbid waters, ionic cadmium will be rapidly scavenged by suspended clays, humic and other organic materials, and various metal oxides. Callahan *et al*. (1979) report concentrations of cadmium complexed to humic particles 5,000 to 50,000 times greater than free ionic cadmium in river water samples. They also noted that numerous studies showed levels of cadmium in the sediments at least an order of magnitude higher than in overlying waters (Metro data for sediments was two orders of magnitude higher than for stream interstitial waters). The higher the water's acidity, the higher the ratio of available free ions. In saltwater, cadmium chloride complexes predominate (EPA, 1980a).

Among the priority pollutant metals, ionic cadmium is second only to mercury as an aquatic toxicant (Forstner and Wittmann, 1981). Low pH and water hardness increase its availability, while higher temperatures and salinity increase its uptake. In laboratory experiments, salmonids appear to have the highest sensitivity of the fish species tested (LC_{50} of 1.75 ppb; hardness = 31 mg/l). This exposure represented waterborne ions; those taken in with food produced limited effects, implying lower intake through the gut than through the gills (EPA, 1980a). Cadmium ions strongly bioaccumulate in many organisms, with plants displaying the most rapid uptake (Callahan et al., 1979).

The very low lethal concentrations reported by the various bioassays (< one ppb acute, Sittig, 1980) and the extremely minute concentrations resulting from computing ambient water quality criteria for soft water (0.6 ppb acute and 0.005 ppb chronic at 20 mg/l $CaCO_3$) suggest cadmium at any measurable level in the environment must be highly toxic. But the natural background level of cadmium reported for pristine soft water lakes in the Sierra Nevada mountains averages 3 ppb (Novotny and Chesters, 1981) and for Wisconsin lakes averages 2.5 ppb (Forstner and Wittmann, 1981). The abundance of natural aquatic life in these lakes proves that cadmium's toxicity, as with all trace metals, is highly dependent upon both its chemical form and its bioavailability.

8. PAHs

(Compiled from Neff, 1979, and Callahan et al., 1979). Among the organic priority pollutants is a family of 16 compounds consisting of clusters of carbon rings; these are the polycyclic aromatic hydrocarbons (also commonly called polynuclear aromatics or PNAs). PAHs derive from a number of sources, some natural, some anthropogenic. The heat and pressure which converted organic matter into such forms as petroleum, coal, and peat also resulted in their containing polynuclear aromatics. Through extraction, refining, and imcomplete combustion of these fossil fuels, PAHs are dispersed into the air, soils, and water. As previous sections on natural background levels have noted, low levels of the various PAHs (one to five ppm) have been found worldwide in both living organisms and their environments, generally credited to anthropogenic sources.

The main routes of entry to the aquatic environment are fallout or rainout of airborne soot particles, surface stormwater runoff, and petroleum spills. Because of their low solubility and hydrophobic character, PAHs rapidly adsorb to organic particles and inorganic material in the receiving water. In several British studies, the concentrations of soluble PAHs represented between two and 16% of the concentration for particulate-bound PAHs. These particles accumulate in bottom sediments and, once deposited, are less subject to photochemical or biological oxidation. Because of this concentration and persistence, sediments often contain levels more than a thousand times greater than the overlying water.

Studies of the uptake of PAHs by organisms from their food or the surrounding sediments indicate that when complexed or adsorbed to other organic materials, PAHs are much less bioavailable than when freely dispersed in the water. Also, many aquatic organisms have the ability to metabolize or detoxify PAHs and/or excrete the compounds and their metabolites rapidly enough to avoid toxic effects (McCain et al., 1982). Food-chain biomagnification is very limited, if it occurs at all.

In laboratory tests, exposure to dissolved PAHs caused acute toxicity to some organisms at concentrations as low as 0.2 ppm. Chronic exposure could result in the animal's producing metabolites which induce tumors. But the carcinogenic effects of PAHs to aquatic organisms in their natural environments is unknown. Human exposure via water or fisheries products is considered insignificant when compared to other types of exposure (charcoal-broiled steak contains 11 to 50 ppb benzo(a)pyrene and cigarette smoke contains high levels of many PAHs, especially those with lower molecular weights [Neff, 1979]).

The physical, chemical, and toxic characteristics of the various PAHs are related to the number of carbon rings they contain. Generally, the strength of the chemical bonds, as well as the molecule's vapor pressure and solubility, decrease with increasing molecular complexity. Those PAHs with two- to three-rings tend to be much more acutely toxic to aquatic life than the four- to six-ring molecules. But the four- to six-ring compounds show a greater potential as mammalian carcinogens.

Figure 27 shows the 16 priority pollutant PAHs by size and provides diagrams of their ring structures.

9. Phthalate Esters

Phthalate acid esters usually are colorless, oily, highly stable liquids having very low volatility and solubility. In addition to their primary use in the production of polyvinyl chloride plastics, they also are employed as industrial oils, defoaming agents in paper production, in munitions, and as bases for cosmetics, fragrances, and pesticides. This variety of uses combined with a large production volume and the phthalates' ease of extraction make them ubiquitous low-level environmental contaminants. The dioctyl phthalate group (including bis-2-ethyl hexyl phthalate) represents approximately 40% of U.S. phthalate production (Sittig, 1980).

Phthalate esters are strongly attracted to organic particles, and, in water, soon settle into the bottom sediments. Due to their high lipophilic nature, phthalates readily accumulate in aquatic organisms but no food-chain biomagnification has been noted. From acute and chronic toxicity data, the phthalate esters show relatively low metabolic disruption. They have not been found to be carcinogenic to animals or man (EPA, 1980a).

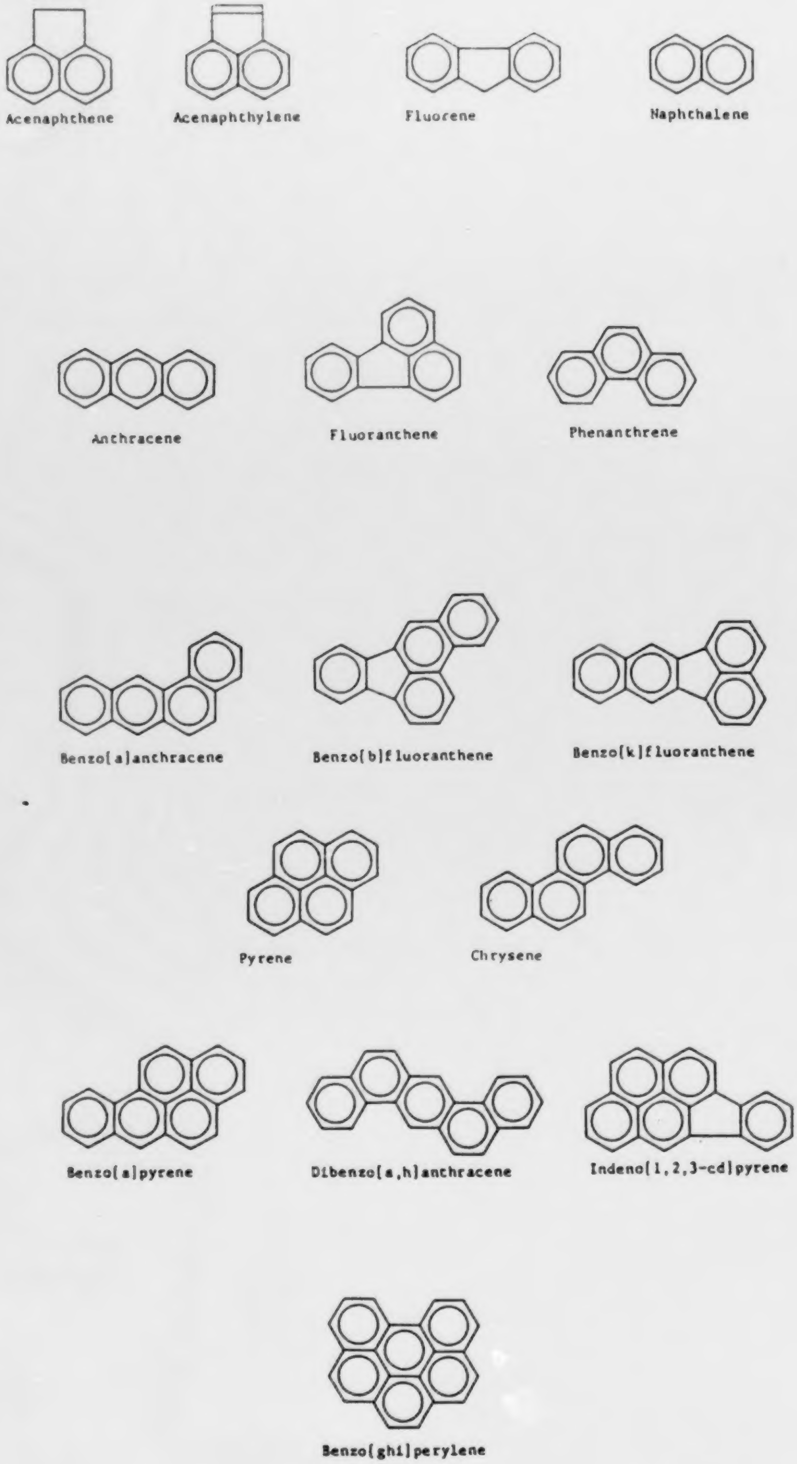

Acenaphthene
Acenaphthylene
Fluorene
Naphthalene
Anthracene
Fluoranthene
Phenanthrene
Benzo[a]anthracene
Benzo[b]fluoranthene
Benzo[k]fluoranthene
Pyrene
Chrysene
Benzo[a]pyrene
Dibenzo[a,h]anthracene
Indeno[1,2,3-cd]pyrene
Benzo[ghi]perylene

Figure 29. THE 16 PRIORITY POLLUTANT PAHs

SECTION V

CONCLUSIONS

1. Stormwater Runoff

- Stormwater runoff sampled from two Bellevue residential areas always contained six of the priority pollutant metals -- arsenic, cadmium, chromium, copper, lead, and zinc -- and occasionally nickel; six were never positively detected -- antimony, beryllium, mercury, selenium, silver, and thallium.

- The average stormwater concentrations of five metals -- cadmium, copper, lead, nickel, and zinc -- exceeded both chronic and acute federal water quality criteria. (However, these criteria are for ambient receiving waters and not undiluted stormwater.)

- Due to dispersal from Tacoma's ASARCO smelter, arsenic concentrations in local runoff are notably higher than most other areas of the country (although below water quality criteria), whereas local runoff concentrations are generally lower for the other metals.

- Differences in runoff metal concentrations were not statistically significant between the three basic urban landuse types: residential, commercial, and industrial. However, runoff from freeway corridors was consistently the highest.

- Nineteen of the 111 organic priority pollutants were observed in residential stormwater runoff; none of the 19 were seen in more than 20% of the samples. Analytical detection limitations explain, at least partially, these low occurrences since observed concentrations were very near these limits.

- In the stormwater runoff, the most frequently detected organics were pesticides such as lindane, α BHC, and pentachlorophenol, and the polycyclic aromatic hydrocarbons (PAHs).

- Among the organic priority pollutants, federal water quality criteria currently exist only for pesticides and PCBs (as a group). All seven pesticides observed in local samples exceeded criteria at least once.

- Considering the limited availability of national data, concentrations of organic compounds seen in local runoff were similar to values reported from across the country.

- Metals and organic compounds in runoff are associated with the fine particles transported with the stormwater. Of the metals studied, only copper and zinc have significant portions in the dissolved fraction (capable of passing a half-micron filter). Studies of the total extractable organics in runoff found a 71 to 96% association with the very fine suspended material.

2. Sources to Runoff

- Of all the many sources of toxicants to urban runoff, motor vehicles are the primary contributors of both metals and organics. Fuel combustion products, lubricant and fuel leakages, and tire and mechanical wear are concentrated in street dust and urban soils. If lifted by rain splash and transported to storm drains, most of these particle-bound and dissolved toxicants will be discharged into the region's streams, rivers, lakes, and bays.

- All of the priority pollutant metals except selenium were identified in the street dust samples. The six metals seen in the highest concentrations in the street dust samples were the same six found in stormwater.

- No clear trends in metal concentrations appeared following an examination of dust samples from different landuse types.

- Metal concentrations in street dust samples from the Metro study area appear to be lower than concentrations reported from other urban studies across the country. The exceptions are arsenic which has consistently been measured in this area's suspended dust, soils, waters, and sediments at levels as high or higher than elsewhere, and lead which is found at unusually high concentrations on Seattle's Harbor Island. Point sources for both metals are smelters.

- The concentrations of metals tend to be highest in the smallest dust-particle fractions, but these same particles account for only a small portion of the total solids load on street surfaces.

- Nearly twice as many organic priority pollutants appear in street dust as in stormwater. Those compounds seen with the highest frequencies and concentrations in street dust were the PAHs and phthalates.

- The few reports describing organic compounds and dust-particle size support the same relationship as noted for metals: most associate with the smallest particle-size fractions.

- While samples of atmospheric suspended particles contained high concentrations of both metals and organics, no direct relationship exists between the finest suspended particles and that material which settles onto urban surfaces, so no correlations could be made with street dust. The atmospheric suspended PAHs were generally the larger, more complex compounds associated with fossil fuel combustion.

3. The Receiving Environment

- Toxicants in streamwater usually travel tightly bound to very fine particles. These particles are flushed rapidly through the stream system during high stormwater flows, when toxicant concentrations can closely approach stormwater values. For example, non-storm interstitial lead concentrations were measured near background levels but during storms these concentrations often rose over ten-fold.

- Natural streambank sediments appear to dilute the toxicant-laden stormwater particles, reducing general stream sediment concentrations to near or, in some cases, below analytical detection limits.

- Arsenic (consistently) and cadmium, chromium, lead, and zinc (occasionally) exceeded natural background concentrations in sediment samples from local urban streams. Concentrations in rural reference stream samples were at or below natural levels for all metals except arsenic.

- The physical properties of erosion, channel scouring and sediment transport are so predominant in urban streams that they overshadow or prevent potential toxicant buildup or toxicant problems.

- This study's samples of Lake Washington sediments contained metal and organic concentrations similar to those detected in the urban streams. Arsenic, copper, lead, mercury, and zinc in the lake sediments frequently appeared with concentrations above background levels; specific organic compounds such as PAHs appear to be elevated in the lake sediments.

- The significance of detecting the priority pollutants at trace levels in water and sediments is difficult to determine. This report and several others have concluded that most of the toxicants readily bind to fine particles which should make them much less likely to be metabolized by aquatic organisms. However, some studies have reported toxic responses to runoff water and recent marine sediment bioassays by Metro and studies of marine bottom fishes by NOAA suggest some metabolic disruptions are occurring. Without further research, no cause and effect relationships can yet be determined.

- For reasons previously cited, urban runoff does not appear to present acute toxicity problems in local urban streams. While chronic problems are possible they have not been locally documented. Runoff into sensitive receiving waters such as small lakes may present a greater concern due to their limited rate of flushing. Again, lack of data prevents accurate documentation.

- The relative contribution of urban runoff to total toxicant burdens in Lake Washington, regional embayments and Puget Sound, as well as to the regional sewerage system in areas of combined sewers, was beyond the scope of this project, but will be addressed in Metro's Toxicant Pretreatment Planning Study.

4. Control Measures

- Because most toxicants are associated with fine particles, techniques that trap these particles should be used where control measures are warranted because of concern for sensitive receiving waters.

- Street sweeping using standard rotary-brush equipment appears to have no significant effect on levels of toxicants in this study area's runoff.

- Most existing detention basins appear ineffective at improving runoff quality; specially-designed detention basins and detention ponds with long holding times have been shown to reduce fine particle loadings and thus control toxicants, but proper maintenance is required to prevent later resuspension and discharge.

- Retention or infiltration basins, when properly designed and maintained, have demonstrated removal of metals and particle-bound organics, but they may allow the more mobile organic solvents to percolate into underlying groundwaters.

- Wetlands and grass-lined channels are able to remove many pollutants but chronic accumulation of toxicants in such areas may pose problems.

- Traditional oil and grease separators have proven ineffective at removing the floatable organics from runoff without frequent maintenance; however, coalescing-plate filters, while expensive, may effectively remove oil and grease, but data on runoff concentrations are lacking.

- In general, little or no data are available on control effectiveness for the priority pollutants in urban runoff.

SECTION VI

RECOMMENDATIONS

The basic issues addressed by this study were: what toxic substances are carried by urban runoff into the receiving-water environment; are any of these stormwater-transported toxicants found in a form and at concentrations capable of harming receiving-water organisms; and what can effectively be done to reduce or prevent such harm if it exists.

In order to make any useful recommendations, one should clearly understand the issues to which they're directed.

Following our extensive literature review and field sampling program we found the second issue above (harm to organisms) much more difficult to evaluate than anticipated. The study couldn't simply measure priority pollutant concentrations in the environment and compare them with a set of precise, unequivocal, and definitive criteria in order to say, "There is, or is not, a problem." Questions over what and where to measure, how to measure, and even whether enough material exists to measure could not be clearly answered. And the handful of criteria available are far from unequivocal. Because this lack of sampling and evaluative data pervades all literature on toxicants in runoff and the receiving environment, and prevents conclusive resolution of the issue at this time, the following recommendations are presented:

- Because a lack of complete and definitive toxicity criteria exists for the priority pollutants (the few criteria which have been created are only for total water concentrations), we recommend that a series of carefully designed bioassays be performed in order to ascertain the effects on aquatic organisms of chronic exposure to toxicants as they would occur in the receiving environment. Exposures should be to toxicant-bound particles suspended in the water column, as well as to sediments with known metal and organic concentrations. The exposure environment should be as close to local ambient conditions as possible in order to evaluate the effects of regional characteristics (the very soft water, for example); local organisms adapted to existing background conditions should be used.

- A physical-chemical evaluation should be made of stormwater as it enters the various receiving waters in order to determine the magnitude of dilution occurring and whether changes take place in the solution-adsorption ratios of the various toxicants. This should provide useful data on exposure and bioavailability of runoff transported toxicants.

- Because the smaller urban lakes often serve a second role as stormwater detention ponds, their vulnerability to toxicants in runoff seems especially high. Their low volumes, limited purging ability, and visual-recreational values require that special monitoring and maintenance be provided to anticipate and prevent toxic problems.

- Since much uncertainty exists concerning the quantity and quality of toxicants entering street surfaces and receiving waters directly from atmospheric sources, a regional study should be conducted of both rainfall and dry deposition to better document these potentially significant pollutant pathways.

- While this study has focused primarily on the concentrations of pollutants in the urban environments and the adjacent receiving waters, the question of total contribution or loading of these toxicants from runoff and other sources is also little understood and worth further investigation, especially in relation to longterm accumulation, toxic exposure and bio-accumulation problems in both the fresh and saltwater habitats.

If it is determined that toxicants from runoff are harming receiving-water organisms and impinging on the desired beneficial uses of a particular water body, then appropriate control measures are warranted to reduce or prevent toxic discharges.

Due to the nature of nonpoint pollution, source control is generally not a realistic option. However, since much of the toxicant loading to stormwater appears to come from motor vehicles, any measures designed to decrease dispersal of lead in exhaust vapors and spillage of lubricating oils should produce some benefits for runoff quality.

This study's specific recommendations are aimed at preventing toxicant-laden materials in stormwater from reaching receiving waters in harmful concentrations. By controlling the very fine suspended particles in runoff, a double benefit is provided: reduced turbidity and reduced toxicant loads.

- Large detention basins specifically designed to trap and settle out the very fine particles are an effective control measure. These can either be permanent ponds, or broad, grassy swales which are only covered with water following larger storms. Both structures can also provide visual and recreational amenities as well; however, periodic maintenance is required to ensure effectiveness and prevent toxicant buildup in the sediments.

- Retention basins are very similar to detention ponds but are used where the volumes of stormwater permit long-term storage for dispersal through soil percolation. Again, these sites can be permanent ponds, or grassy fields filled with water only after storms. Scenic and recreational potential also exists for retention basins. Concern must be given to the concentrations of organic solvents contained in the stormwater. These highly mobile compounds are suspected of passing through the sub-soils and into underlying groundwater.

- Wide, grassy areas should be designed along major roadways as buffer zones which effectively filter much of the particulate matter from stormwater that flows over it. Stormwater channels can also be improved by a grassy cover. Periodic maintenance should be performed to ensure effectiveness and prevent buildup of sediments.

- Specially designed oil and grease separators, such as coalescing-plate filters, should be installed to treat stormwater from areas where the toxicants associated with floatable films and emulsions are known to collect and where the receiving-water environment is especially sensitive.

- Continued research should be conducted on evaluating and improving existing control methodology and designing new technology for control and removal of toxicants in stormwater.

APPENDIX A

QUALITY ASSURANCE/QUALITY CONTROL

All scientific work in which samples are collected and analyzed and data are interpreted requires some level of effort to ensure reliability of the information generated. Sampling and analysis for trace levels of metals and organic compounds in the environment demand a very rigorous quality assurance program to prevent contamination throughout the process and to avoid false positive identifications in the analytical procedures. As described in U.S. EPA (1982c), "data must withstand rigorous scrutiny of all aspects of its generation in order to be considered accurate, precise, complete, comparable to data generated on other projects or collected at other times, and legally and scientifically defensible."

Quality assurance (QA) refers to the whole range of actions taken in a project to guarantee the highest standards of reliability of the resultant data. These actions range from selection of sampling sites to sample container cleaning to shipping procedures to the detailed quality control protocols in the laboratory (see below) to data review before computer entry. The QA program for the Toxicant Inventory is described in the Experimental Design section of Chapter II.

Quality control (QC) refers to the specific actions involved in sample analysis to identify problems and ensure data validity. Our QC program generally followed that outlined in U.S. EPA (1980d) and included the following components:

- Field blanks;
- Laboratory method blanks;
- Replicate samples; and
- Surrogate spiking of samples.

Results follow.

1. Field Blanks

A field blank is a deionized distilled water sample treated exactly as the real field samples, including contact with sampling equipment and glassware and passage through all handling and shipping procedures to check for any contamination along the process.

Tables A1 and A2 present results of field blank analyses for metals and organics, respectively. Zinc, copper and lead appeared in more than half the blanks and resulted in some data point rejections, as noted in the tables in Section III. Phenol and the phthalates were the only organic contaminants of note in the field blanks.

Special blanks were run of the glass fiber filters used in the high-volume air samplers. As shown in Table A3, both sets of filters had some metal contaminants and the older set had low levels of phthalate contamination. These results are factored into the data reported in Section III.

2. Laboratory Method Blanks

A method blank is a deionized distilled water sample handled exactly as the real field samples in the laboratory, through sample storage, preparation, extraction and instrument analyses. Any laboratory contamination (such as the notorious methylene chloride, a common solvent) or instrument errors (such as false positive identifications) can be detected.

Tables A4 and A5 present results of method blank analyses for metals and organics, respectively. Trace contamination or false positives for silver and mercury resulted in rejection of some data points in the runoff results. Methylene chloride and phthalate contamination in the laboratory is nearly ubiquitous. The pesticide observations are most probably false positive identifications.

3. Replicate Samples

Eleven pairs of split samples were analyzed as replicates to check the precision of the analytical methods.

Results are shown in Tables A6 and A7 for metals and organics, respectively. All replicates showed very close agreement for the metal analyses. Organic results, while exhibiting less precision as expected, still were generally quite close.

4. Surrogate Spikes

Surrogates are compounds which are chemically similar to some of the priority pollutants but not likely to be found in environmental samples (U.S. EPA, 1980c). Known quantities are added to real field samples to test recovery rates or other analytical problems.

Metal spikes were added to two sediment samples; results are shown in Table A8. Other than antimony and thallium, recoveries were within acceptable limits.

Organic surrogates were added to every sample. Tables A9 and A10 present results for water and sediment samples, respectively. Mean results are within generally accepted levels for GC/MS analyses. Volatile results are quite close to 100%; the base/neutral fraction is in the 60 to 90% range for water samples and "whatever you can get" for sediments (Farlow, personal communication).

TABLE A1. METAL CONTAMINATION IN FIELD BLANKS--URBAN RUNOFF AND INTERSTITIAL STREAMWATER SAMPLES. Data are concentrations in μg/l = ppb.

Sample Type[a]:	IS	IS	UR	UR	UR	UR	UR
Sample #:	27	40	41	51A	51B	51C	51D
Antimony	--	--	--	--	--	--	--
Arsenic	--	--	--	2	--	--	--
Beryllium	--	--	--	--	--	--	--
Cadmium	--	--	--	--	0.1	--	0.2
Chromium	--	--	--	--	--	--	--
Copper	--	--	2	2	5	11	11
Lead	--	--	--	1	1	1	2
Mercury	--	--	--	--	--	--	--
Nickel	--	--	--	--	--	--	--
Selenium	--	--	--	--	--	--	--
Silver	--	--	--	--	--	--	--
Thallium	--	--	--	--	--	--	--
Zinc	--	2	7	--	2	10	15
Cyanides	--	--	--	--	--	--	--

[a] Sample types: IS = Interstitial Streamwater; UR = Urban Runoff

TABLE A2. ORGANIC CONTAMINATION IN FIELD BLANKS -- URBAN RUNOFF AND INTERSTITIAL STREAMWATER SAMPLES. Data are concentrations in $\mu g/l$ = ppb.

Sample Type[a]: Sample #:	UR 14	UR 15	IS 16	IS 17	UR 18	UR 19	UR 20	UR 21	UR 22	UR 23	IS 27	IS 40	UR 41	UR 42	UR 43
ACID:															
phenol	7	8	3	2	6	--	6	--	--	--	--	--	--	--	--
BASE/NEUTRAL:															
bis (2-ethyl hexyl) phthalate	130	100	4	13	5	9	33	240	--	--	57	--	120	--	--
di-n-butyl phthalate	2	2	1	1	--	--	1	--	--	--	--	--	--	--	--
butyl-benzyl phthalate							6	8	--	--	--	--	--	--	--
fluoranthene	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--

[a]Sample types: UR = Urban Runoff, IS = Interstitial Streamwater.

TABLE A3. ORGANIC AND METAL CONTAMINATION IN HIGH-VOLUME AIR FILTER BLANK SAMPLES. Data are concentrations in μg/gram = ppm.

	39 blank	(level seen in 39 for comparison)	56 blank	(level seen in 56 for comparison)
ORGANICS:				
bis(2-ethylhexyl) phthalate	14	(89)	--	(4.9)
butyl benzyl phthalate	10	(13)	--	(---)
di-n-butyl phthalate	15	(40)	--	(1.2)
di-ethyl phthalate	5	(8)	--	(---)
METALS:				
antimony	6	(56)[a]	--	(1.9)
arsenic	2	(360)[a]	2	(51)
beryllium	--	(--)	0.9	(---)
cadmium	1	(23)[a]	--	(2.5)
copper	16	(950)[a]	--	(60)
lead	46	(1700)[a]	--	(390)
nickel	--	(200)[a]	46	(21)
selenium	7	(45)[a]	0.7	(1.4)
silver	0.7	(4.2)[a]	--	(0.7)
zinc	18	(3100)[a]	32	(140)

[a] Sample #39 metal results were already corrected for blank contamination by laboratory.

Table A4. METAL LABORATORY METHOD BLANK SAMPLES. Underlined entries are observed contamination or false positive values; other (less than) entries are detection limits. All values are concentrations in µg/l = ppb for water blank samples.

Sample Type	WATER							SEDIMENT[a]								
Sample #	22-23	40	41	42-43	51A-51G	55A-55B	62-63	34	35	44-46	47-50	52-54	56-60	64-67	68-74	76-81
Antimony	< 3	<3	< 3	< 3	< 3	< 1	<1	<2	<2	< 5	< 30	<10	5	< 2	< 5	< 6
Arsenic	< 2	<2	< 2	< 2	< 2	< 2	<2	<3	<3	< 10	< 20	<10	16	< 10	10	<10
Beryllium	< 0.3	<0.3	< 0.3	< 0.3	< 0.3	< 0.1	<0.1	<0.08	<0.08	< 10	< 6	1.9	< 0.6	< 6	< 10	<10
Cadmium	< 0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1	<0.01	<0.01	< 20	< 10	< 0.4	<50	< 50	< 40	<30
Chromium	< 1	<1	< 1	< 1	< 1	2	<1	<1	<1	<200	< 60	9	<50	< 50	< 40	<40
Copper	< 8	<1	< 1	< 1	< 1	< 4	<4	1.6	1.6	< 20	< 40	<40	<40	< 40	< 20	<30
Lead	< 10	<1	< 1	< 1	< 1	< 1	<1	0.6	0.6	< 30	<200	< 5	<200	<200	< 80	<200
Mercury	0.5	<1	< 1	< 0.5	< 0.5	< 0.5	<0.5	<0.5	<0.5	< 1	< 1	< 1	< 1	< 0.5	< 0.5	< 1
Nickel	< 1	<6	< 8	< 1	< 3	< 3	<7	<7	<7	< 30	< 60	<60	<60	< 60	< 30	<60
Selenium	< 2	<2	< 2	< 2	< 2	< 2	<2	<3	<3	< 10	< 10	<20	< 6	< 5	< 6	< 7
Silver	0.5	<0.2	< 0.2	< 0.2	< 0.2	0.5	0.5	<0.5	<0.5	< 1	< 10	1	< 0.2	< 20	< 20	<20
Thallium	< 1	<1	< 1	< 1	< 1	< 1	<1	<0.5	<0.5	< 20	< 5	< 3	< 2	< 5	< 5	<50
Zinc	< 5	<1	< 1	< 1	< 1	< 1	<1	<1	<1	< 7	< 10	< 8	<10	< 5	6	<10
cyanides	< 5	<10	< 5	<10	---	---	<5	<5	<5	< 10	< 10	< 5	< 5	< 5	< 5	< 5

[a] Method blanks for sediment analyses are water samples run at the same instrumentation levels; results are in µg/l, not µg or mg/kg.

TABLE A5. ORGANIC LABORATORY METHOD BLANK SAMPLES. Entries are observed contamination or false positive values in μg/l or μg/kg = ppb.

	23	34	35	40	41	42–43	44–46	47–50	52–54	55A–55B	56–60	61–63	64–67	68–74	76–81
VOA:															
methylene chloride	--	--	--	--	--	--	--	--	--	--	69	--	24	--	--
BASE/NEUTRAL =															
bis(2-ethyl hexyl) phthalate	--	29	28	37	--	--	--	--	--	--	280	--	--	--	--
butyl benzyl phthalate	--	--	--	--	--	--	--	54	--	--	--	--	--	--	--
di-n-butyl phthalate	--	--	--	--	--	--	--	--	--	--	--	--	--	21	--
PESTICIDE:															
a-endosulfan	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--
γ-BHC	--	--	--	--	--	--	--	--	--	0.1	--	--	--	--	--
heptachlor	--	--	--	--	--	--	--	--	--	--	--	--	0.007	--	--

Table A6. METAL RESULTS OF REPLICATE SAMPLE ANALYSES. Data are concentrations in ppb (µg/l) for water samples and in ppm (mg/kg) for sediment samples; less than (<) entries are detection limits.

	WATER (µg/l=ppb)						SEDIMENT (mg/kg=ppm)															
Sample Type^a:	IS		UR		UR		SD		SS		SD		LS		SS		SS		SS		SD	
Sample #:	16	17	22	22R	23	23R	11	12	24	25	30	31	48	49	52	52R	53	53R	54	54R	57	60
Antimony	< 2	< 2	< 3	< 3	< 3	< 3	< 1	< 1	< .2	< .2	< .2	1.2	< 1	< 1	< .5	< .5	< .5	< .5	< .5	< .5	1.5	2.0
Arsenic	40	40	33	37	27	27	18	39	6	8	16	22	6.1	6.8	13	16	5.9	4.8	15	14	34	47
Beryllium	.5	.5	< .3	< .3	< .3	< .3	.33	.34	.11	.12	.17	.19	.02	.03	.18	.19	.08	.06	.18	.17	.29	.3
Cadmium	1.2	1.5	1.3	1.3	1.1	1.2	.6	.8	.07	.08	.66	.65	.15	.12	.27	.35	.06	.06	.26	.25	.9	2.0
Chromium	41	39	9	10	9	10	20	30	68	52	120	160	9.6	9.6	42	37	14	13	42	39	40	59
Copper	68	63	46	46	28	28	31	38	4.7	4.9	52	69	11	12	10	10	1.5	1.7	11	10	84	150
Lead	240	240	460	430	370	370	820	520	2	2.9	150	110	30	30	49	25	1.5	1.6	22	18	380	540
Mercury	< 1	< 1	.5	< .5	< .5	< .5	.033	.042	< .05	< .05	< .05	.10	.04	.03	.01	< .01	< .01	< .01	.01	.01	.02	.09
Nickel	20	20	20	20	27	27	20	28	9	9	35	35	9.1	9.6	29	24	4.5	4.5	15	15	29	44
Selenium	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 3	< 3	< 3	< 3	< .1	< .1	< .2	< .2	< .2	< .2	< .2	< .2	< .6	< .6
Silver	13	.6	< .5	< .5	< .5	.8	.01	.04	< .5	< .5	< .5	< .5	< .04	< .04	< .02	< .02	< .02	< .02	< .02	< .02	.3	.5
Thallium	< 1	< 1	< 1	< 1	< 1	< 1	.26	.29	< 1	< 1	< 1	< 1	< .2	< .2	< .1	< .1	< .1	< .1	< .1	< .1	< .2	< .2
Zinc	280	250	250	230	240	240	180	170	29	29	330	400	31	32	57	56	16	17	59	56	110	970
Cyanide	< 10	< 10	< 5	< 5	< 5	—	< .1	≤ .1	< .2	< .2	.3	.4	< .05	< .05	< .05	< .05	< .05	< .05	.1	.07	< .05	.09

[a] Sample Type: IS=Interstitial Streamwater, UR=Urban Runoff, SD=Street Dust, SS=Stream Sediment, LS=Lake Sediment.

Table A7. ORGANIC RESULTS OF REPLICATE SAMPLE ANALYSES. All data are concentrations in ppb (μg/l for water samples and μg/kg for sediment samples).

Sample Type[a]:	SD		IS		SS		SD		LS		SS		SS		SS		SD	
Sample #:	11	12	16	17	24	25	30	31	48	49	52	52R	53	53R	54	54R	57	60
VOA:																		
chloroform	5	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ethylbenzene	5	25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
toluene	4	8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
benzene	--	--	22	24	--	--	--	32	--	--	--	--	--	--	--	--	10	--
1,1,1-trichloroethane	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	16
ACID:																		
phenol	--	--	--	--	--	--	--	200	--	--	--	--	--	--	--	--	--	--
2,4-dimethylphenol	--	--	--	--	--	--	--	--	--	--	--	--	--	--	43	110	--	--
BASE/NEUTRAL:																		
FLUORANTHENE	780	1200	--	--	30	--	1500	1700	--	--	--	--	--	--	88	55	1900	2200
PHENANTHRENE	640	880	--	--	26	--	1500	1500	--	--	--	--	--	--	51	48	1900	2600
PYRENE	630	1000	--	--	28	--	1500	1600	--	--	--	--	--	--	93	72	1900	2500
BENZO(a) ANTHRACENE	--	--	--	--	--	--	240	550	--	--	--	--	--	--			660	850
BENZO(a) PYRENE	--	--	--	--	--	--	450	900	--	--	--	--	--	--	54	21	690	--
BENZO(k) FLUORANTHENE	--	--	--	--	--	--	270	1300	--	--	--	--	--	--	92	65	1200	--
CHRYSENE	--	--	--	--	--	--	1200	980	--	--	--	--	--	--	69	74	1000	1300
ANTHRACENE	--	--	--	--	--	--	320	370	--	--	--	--	--	--	--	--	--	--
BIS(2-ethylhexyl) PHTHALATE	--	--	--	--	39	250	--	43,000	--	--	--	--	--	--	--	--	33,000	74,000
BUTYL-BENZYL PHTHALATE	--	--	--	--	320	--	2500	2200	--	--	--	--	--	--	--	--	--	--
DI-N-BUTYL PHTHALATE	--	--	--	--	--	--	490	570	--	--	--	--	--	--	--	--	--	--
DI-N-OCTYL PHTHALATE	--	--	--	--	--	--	700	270	--	--	--	--	--	--	--	--	--	--
PESTICIDE:																		
4,4'- DDD	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
α-BHC	--	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
γ-BHC	--	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[a] Sample type: SD=Street Dust, IS=Interstitial Streamwater, SS=Stream Sediment, LS=Lake Sediment.

Table A8. METAL SPIKE RECOVERIES (AS PERCENT)--SEDIMENT SAMPLES

Sample Type [a]:	LS	LS		Standard
Sample # :	64	66	Mean	Deviation
Antimony	40%	4%	22%	±25
Arsenic	140	140	140	±0
Beryllium	80	88	84	±6
Cadmium	120	120	120	±0
Chromium	85	80	82	±4
Copper	99	96	98	±2
Lead	120	88	104	±23
Mercury	110	100	105	±7
Nickel	98	93	96	±4
Selenium	87	100	94	±9
Silver	85	85	85	±0
Thallium	31	55	43	±17
Zinc	80	100	90	±14

[a] Sample type: LS = Lake Sediment

Table A9. ORGANIC SURROGATE SPIKE RECOVERIES (AS PERCENT) -- RUNOFF AND INTERSTITIAL WATER SAMPLES.

Sample Type[a]: Sample #:	UR 5	UR 6	UR 7	UR 14	FB 14B	UR 15	FB 15B	IS 16	FB 16B	IS 17	FB 17B	UR 18	FB 18B	UR 19	FB 19B	UR 20	FB 20B	UR 21	FB 21B	UR 22
VOA:																				
D_6-Benzene	104%	115	100	105	--	110	--	110	--	105	--	--		--		105		105		120
m-Difluorobenzene	104	117	100	100	--	105	--	100	--	100	--	--		--		--		--		--
d_8-Toluene	102	115	103	100	--	100	--	100	--	105	--	--		--		110		105		135
d_4-1,2-Dichloroethane	--	--	--	--		--	--	--	--	--	--	--		--		100		105		100
ACID:																				
d_5-Phenol	41	38	50	45	54	43	56	65	72	54	50	65	74	54	45	57	76	72	48	23
d_4-2-Nitrophenol	--	--	--	--	66	--	--	--	--	--	--	60	83	21	48	63	93	61	40	56
BASE/NEUTRAL:																				
d_5-Nitrobenzene	55	58	44	88	76	90	68	76	84	85	62	81	87	62	64	99	95	89	54	31
1-Fluoronaphthalene	57	53	63	87	--	95	--	84	--	86	--	--	--	--	--	--	--	--	--	--
d_{10}-Fluorene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
d_8-Naphthalene	--	--	--	--	--	--	--	--	--	--	--	67	100	61	69	99	75	83	47	30
d_{12}-Chrysene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[a] Sample type: UR=Urban Runoff; IS=Interstitial Streamwater; FB=Field Blank.

Table A9 (Continued). ORGANIC SURROGATE SPIKE RECOVERIES (AS PERCENT) -- RUNOFF AND INTERSTITIAL WATER SAMPLES.

Sample Type[a]: Sample #:	FB 22B	UR 23	FB 23B	IS 27	FB 27B	IS 40	FB 40B	UR 41	FB 41B	UR 42	FB 42B	UR 43	43B	Mean	Standard Deviation	Acceptable Range $(\bar{x} \pm 3s)$
VOA:																
d_6-Benzene	125	120	125	95	105	95	105	105	80	105	105	105	95	106%	±10	76 - 136
m-Difluorobenzene		--	--	-	--	--	--	--	--	--	--	--	--	104	±6	86 - 122
d_8-Toluene	150	130	145	95	105	90	130	85	65	100	105	105	60	106	±22	40 - 172
d_4-1,2-Dichloroethane	105	105	115	90	105	100	105	125	95	120	105	100	90	104	±10	74 - 134
ACID:																
d_5-Phenol	5	34	8	88	69	66	72	100	94	66	86	57	73	58	±22	0 - 124
d_4-2-Nitrophenol	20	78	35	82	75	109	128	100	110	61	79	51	65	69	±28	0 - 153
BASE/NEUTRAL:																
d_5-Nitrobenzene	15	43	24	87	70	68	63	62	67	81	106	69	88	70	±21	7 - 133
1-Fluoronaphthalene	--	--	--	--	--	--	--	--	--	--	--	--	--	75	±17	24 - 126
d_{10}-Fluorene	--	--	59	--	49	65	62	54	56	75	87	54	72	63	±12	27 - 99
d_8-Naphthalene	20	40	35	58	36	69	59	72	79	82	94	59	86	65	±23	0 - 134
d_{12}-Chrysene	--	--	74	--	61	75	81	120	200	79	92	75	91	95	±40	0 - 215

[a] Sample type: UR=Urban Runoff; IS=Interstitial Streamwater; FB=Field Blank.

Table A10. ORGANIC SURROGATE SPIKE RECOVERIES (AS PERCENT) -- SEDIMENT SAMPLES.

Sample Type[a]: Sample #:	SD 11	SD 12	SD 13	SS 24	SS 25	SS 26	SS 28	SS 29	SD 30	SD 31	SD 32	SD 33	SD 34	SS 35	SS 36	SS 37	SS 38
VOA:																	
d_6-Benzene	115%	96	106	90	110	89	110	110	99	82	120	110	100	130	120	97	110
M-Difluorobenzene	92	76	100	--	--	--	--	--	--	--	--	--	--	--	--	--	--
d_8-Toluene	110	94	91	110	110	110	120	120	110	95	110	90	110	140	180	110	130
d_4-1,2-Dichloroethane	--	--	--	85	87	95	41	98	74	34	100	97	12	120	140	65	78
ACID:																	
d_5-Phenol	0	0	55	13	57	42	56	68	70	108	0	108	192	80	75	39	71
d_4-2-Nitrophenol	--	--	--	15	15	57	6	82	1	0	2	0	12	75	69	75	63
BASE/NEUTRAL:																	
d_5-Nitrobenzene	3	5	11	22	10	75	3	80	80	0	90	19	70	67	71	67	67
1-Fluoronaphthalene	55	80	80	--	--	--	--	--	--	--	--	--	--	--	--	--	--
d_{10}-Fluorene	--	--	--	20	50	55	55	55	64	68	82	77	123	92	92	85	100
d_8-Naphthalene	--	--	--	17	49	44	50	45	105	100	110	100	160	69	83	73	92
d_{12}-Chrysene	--	--	--	28	76	65	71	76	82	10	94	88	147	100	92	92	64

[a] Sample types: SD=Street Dust; SS=Stream Sediment; LS=Lake Sediment.

Table A10 (Continued). ORGANIC SURROGATE SPIKE RECOVERIES (AS PERCENT) -- SEDIMENT SAMPLES

Sample Type[a]:	LS	LS	LS	LS	LS	LS	LS	SS	SS	SS	SD	SD	SD	SD	SD	LS	LS
Sample #:	44	45	46	47	48	49	50	52	53	54	57	58	59	60	61	64	65
VOA:																	
d_6-Benzene	110	100	125	115	115	125	105	100	100	108	140	135	160	135	93	83	83
M-Difluorobenzene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
d_8-Toluene	85	75	92	100	105	110	90	100	83	100	110	80	115	95	93	77	77
d_4-1,2-Dichloroethane	85	90	120	125	125	140	100	110	108	108	155	155	170	140	88	80	70
ACID:																	
d_5-Phenol	90	64	88	83	50	49	80	29	79	71	71	71	123	123	143	44	50
d_4-2-Nitrophenol	11	11	14	0	0	0	0	21	64	0	0	0	0	0	0	12	10
BASE/NEUTRAL:																	
d_5-Nitrobenzene	75	57	61	48	2	15	0	60	60	70	37	0	0	55	0	17	20
1-Fluoronaphthalene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
d_{10}-Fluorene	98	74	88	79	75	79	79	92	75	92	129	112	171	129	124	70	65
d_8-Naphthalene	85	70	75	80	65	85	80	62	62	85	169	156	194	181	94	50	45
d_{12}-Chrysene	82	66	82	91	82	91	91	96	73	81	191	163	202	73	112	100	65

[a] Sample types: SD=Street Dust; SS=Stream Sediment; LS=Lake Sediment.

Table A10 (Continued). ORGANIC SURROGATE SPIKE RECOVERIES (AS PERCENT) -- SEDIMENT SAMPLES

Sample Type[a]: Sample #:	LS 66	LS 67	LS 68	SS 69	SS 74	SS 76	SS 77	SS 78	SS 79	SS 80	SS 81	Mean	Standard Deviation	Acceptable Range ($\bar{x} \pm 3s$)
VOA:														
d_6-Benzene	77	83	100	73	117	97	83	73	111	67	100	105%	± 19	48 - 162
M-Difluorobenzene	--	--	--	--	--	--	--	--	--	--		89	± 12	53 - 125
d_8-Toluene	73	80	80	90	83	98	95	140	95	120	110	102	± 20	42 - 162
d_4-1,2-Dichloroethane	67	67	93	80	93	97	88	54	91	61	90	95	± 33	0 - 194
ACID:														
d_5-Phenol	94	40	34	61	28	30	38	16	32	30	28	62	± 39	0 - 179
d_4-2-Nitrophenol	41	0	0	32	0	46	42	29	28	20	15	21	± 26	0 - 99
BASE/NEUTRAL:														
d_5-Nitrobenzene	22	20	0	29	0	20	22	13	8	11	7	33	± 30	0 - 123
1-Fluoronaphthalene	--	--	--	--	--	--	--	--	--	--	--	72	± 14	30 - 114
d_{10}-Fluorene	46	100	48	72	38	61	58	48	60	47	39	78	± 30	0 - 168
d_8-Naphthalene	50	60	64	77	47	64	59	65	74	53	41	81	± 39	0 - 198
d_{12}-Chrysene	65	48	24	32	22	61	67	51	60	51	40	80	± 40	0 - 200

[a] Sample types: SD=Street Dust; SS=Stream Sediment; LS=Lake Sediment.

APPENDIX B

AITCHINSON'S DELTA DISTRIBUTION

A common problem in data analysis of trace contaminant studies is statistical analyses of data sets which include true zeroes and, even more problemmatical, data sets which include "less than" values. These latter values represent detection limits and are referred to in the statistician's lexicon as "left-censored" values, because the left tail of the normal curve is artificially censored by the lower limit of detection...as shown in Figure B1. True values may, and in fact are assumed to, exist to the left of this line, if the population's distribution is normal or log normal.

A variety of methods have been employed with such data sets in statistical descriptions such as calculations of means. Common practices include 1) using zero for all non-detected values; 2) using the detection limit for all non-detected values; 3) using some arbitrary fraction of the detection limit such as 1/2 or 1/10; and 4) ignoring all non-detected values and calculating means from the detected values only. As can be seen in Figure B2, these methods all result in different values for the mean, some lower and some higher than the elusive "true" sample mean.

One method to estimate more accurately this "true" mean is called the delta distribution, introduced by Aitchison (1955) and described further in Aitchison and Brown (1969). The following brief discussion was taken from Owen and DeRouen (1980), who present an application of this and another technique to a data set similar to ours.

The delta distribution is a lognormal model in which a proportion, δ, of the observations may be zeroes or non-zero values which follow the curve with mean μ and variance σ^2. The true mean (K) of this distribution is given by:

$$K = (1 - \delta) \exp (\mu + 1/2\sigma^2)$$

For a sample of n observations (Z_i, i = 1, 2, ..., n) with M_o zero values and $M_1 = M - M_0$ non-zero values, and $Y_i = \ln (Z_i)$, Aitchinson's estimator of the mean, M_A, is given by

$$M_A = (1 - \hat{\delta}) \exp (\hat{\mu}) \psi_{n_1} (1/2 \hat{\sigma}^2)$$

where

$$\hat{\delta} = n_0/n,$$

$$\hat{\mu} = n_1^{-1}\sum_{i=1}^{n_1} y_i = \bar{y},$$

$$\hat{\sigma}^2 = (n_1 - 1)^{-1}\sum_{i=1}^{n_1} (y_i - \bar{y})^2$$

and ψ_1 (t) is a Bessel Function defined by

$$\psi_1(t) = 1 + \frac{l-1}{l}t + \frac{(l-1)^3}{l^2 2!}\frac{t^2}{l+1} + \frac{(l-1)^5}{l^3 3!}\frac{t^3}{(l+1)(l+3)} + \cdots$$

The variance of M_A is then given by

$\mathrm{var}_{est}(M_A)$ =

$$n^{-1} \exp(2\hat{\mu} + \hat{\sigma}^2)[\hat{\delta}(1 - \hat{\delta}) + 1/2\,(1 - \hat{\delta})(2\hat{\sigma}^2 + \hat{\sigma}^4)]$$

and the standard deviation, of course, is $\sqrt{\mathrm{var}_{est}(M_A)}$.

For data sets with percent occurrence or observation between 50 and 100, Aitchison's delta distribution was used to calculate the mean and the standard deviation in this study.

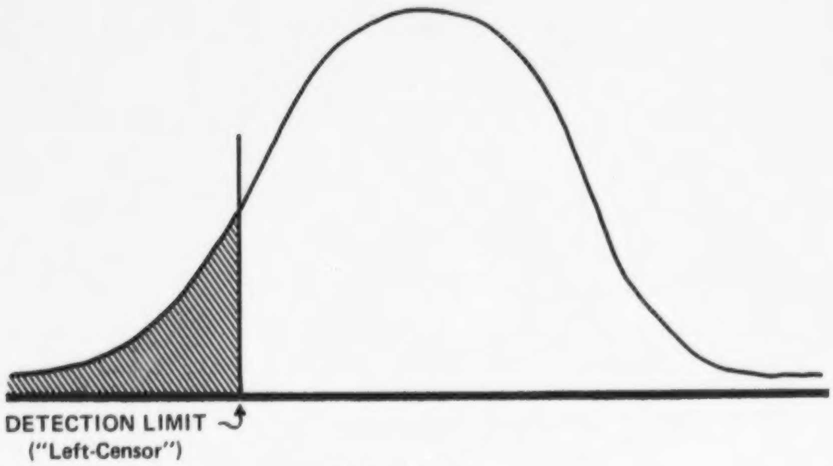
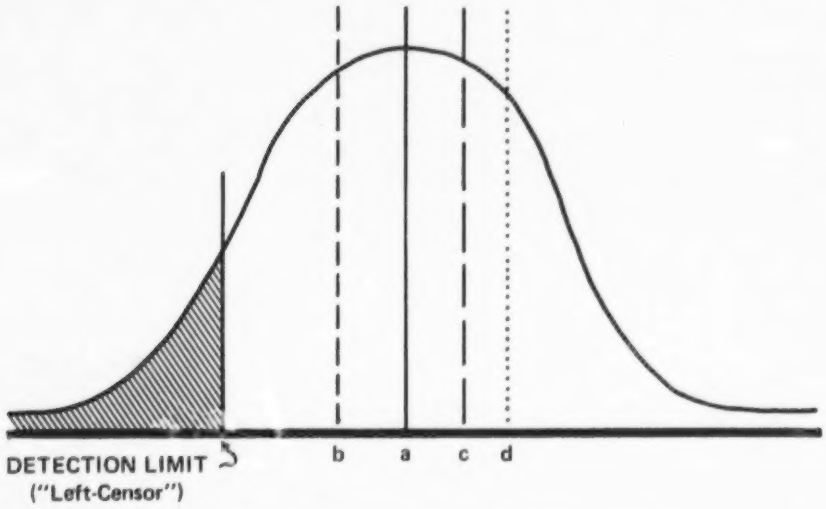

DETECTION LIMIT
("Left-Censor")

Figure B1.
A LEFT-CENSORED CURVE


DETECTION LIMIT
("Left-Censor")
b
a
c
d

[a] Estimate of True Population Mean By Delta Distribution, which Constructs Left Tail of Curve Based on Detected Values.

[b] Calculation of Mean Using Zero for Non-Detected Values.

[c] Calculation of Mean Using Detection Limit for Non-Detected Values.

[d] Calculation of Mean Ignoring Non-Detected Values, Reducing n to Detected Values Only.

Figure B2.
EXAMPLES OF VARIOUS METHODS FOR CALCULATION OF THE MEAN OF A LEFT-CENSORED CURVE

APPENDIX C

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